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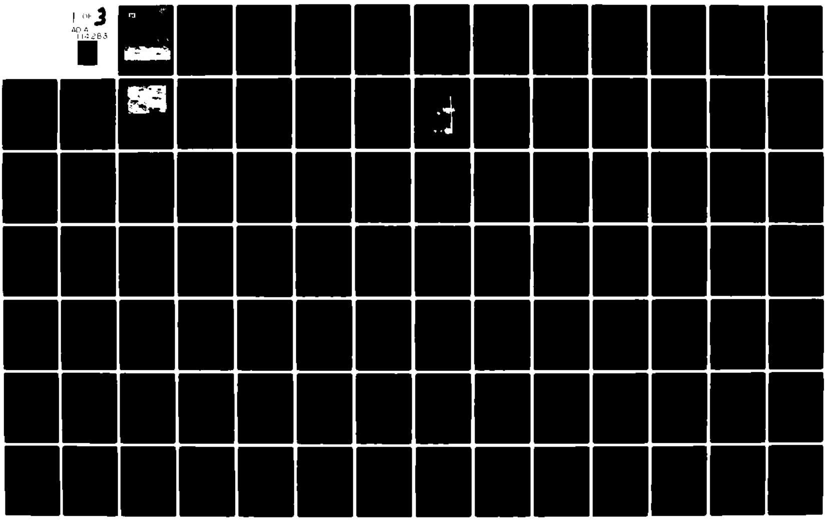

TECHNICAL REPORT HL-82-5

BALTIMORE HARBOR AND CHANNELS DEEPENING STUDY

Chesapeake Bay Hydraulic Model Investigation

by

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Public Law 91-611, through Section 101 of the 1970 Rivers and Harbors Act, authorized a plan of improvement to deepen the existing navigation channels to the Port of Baltimore from 42 ft to 50 ft and to extend the channels to the natural 50-ft-depth curves. Tests on the Chesapeake Bay hydraulic model were conducted to specifically investigate possible changes in the hydrodynamic characteristics of velocity, salinity, and tidal elevations associated with

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20. ABSTRACT (Continued).

the proposed channel enlargements. Changes in these parameters can result in changes to estuarine circulation and dynamics, sedimentation rates and patterns; can affect biological communities and distributions; and can affect dispersion of pollutants and nutrients.

The present investigation included a series of base tests using the verified model with the existing Baltimore Harbor and approach navigation channels at 42 ft plus a 2-ft dredging tolerance. After these tests were completed, the channels were remolded to the new authorized 50-ft depth plus a 2-ft dredging tolerance, and a series of compatible plan tests were similarly performed for comparison purposes. Velocity and salinity were tested individually under different modes or techniques of model operation. Velocity measurements were taken at 13 selected stations while maintaining constant freshwater discharges and repetitive cosine tides. Salinity and tide height measurements were collected at 68 and 10 locations, respectively, during dynamic testing associated with time-varying boundary conditions.

No major plan-to-base velocity differences were apparent in the steady-state comparisons; however, slight trends in velocity characteristics may indicate subtle variations in the hydrodynamics of the system. A small shift in flow distribution (slightly higher flood and lower ebb velocities comparing plan tests with base tests) at lower bay stations below the Potomac River indicates the possibility of additional salt intrusion into the main estuary along the deepened channel. No shift in flow distribution was identified for upper bay or Patapsco River stations that could be used to substantiate or refute changes to, or the presence of, a two- or three-layer flow circulation pattern.

Salinity differences associated with channel deepening are indicated comparing the dynamic base and plan tests. For the purposes of this study, stations demonstrating "appreciable" plan-to-base salinity differences are defined as those stations with 10 percent or more of their surface, middle, or bottom depth comparison values greater than ±2 ppt. Lower main bay stations, below Kent Island, illustrate a slight trend of saltier deep water during the plan test although plan minus base differences are not generally greater than the defined appreciable level. Stations in the bay entrance and York Spit Channel area are the only lower main bay stations to indicate appreciable differences, generally with saltier surface values during the plan test. The James and York Rivers indicate appreciable salinity intrusion decreases during the plan test.

Major salinity differences were found at upper bay stations from Kent Island and above. The water column during the plan test is more stratified with fresher surface values and saltier middepth and bottom values compared with the base test. Plan minus base differences increase progressing up the deepened channel in the main upper bay and the Patapsco River. The largest salinity variations occur in the deepened Patapsco River channel where more than 55 percent of the bottom values increased by more than 5 ppt with the largest increases greater than 10 ppt. Salinity differences were found to decrease with distance from the deepened channels and at shallower water stations.

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PREFACE

Through Section 101, Public Law 91-611, of the 1970 Rivers and Harbors Act, Congress authorized a plan of improvement to deepen the existing channels and approaches to Baltimore Harbor. The U. S. Army Engineer District, Baltimore (NAB), requested the U. S. Army Engineer Waterways Experiment Station (WES) to conduct a hydraulic model study to investigate hydrodynamic changes associated with the proposed channel deepening to the presently authorized depth of 50 ft.

This study was performed 20 July through 29 October 1978, at the Chesapeake Bay Model, Stevensville, Maryland, Estuaries Division, Hydraulics Laboratory, WES, by personnel of the Chesapeake Bay Model Branch, WES, and personnel of Acres American, Inc., contractor to WES for operation of the model. This study was accomplished under the general direction of Mr. H. B. Simmons, Chief of the Hydraulics Laboratory, Mr. F. A. Herrmann, Jr., Assistant Chief of the Hydraulics Laboratory, Mr. R. A. Sager, Chief of the Estuaries Division, and Dr. J. W. Hayden, Project Manager for Acres American, Inc. Testing was conducted under the direct supervision of Mr. D. F. Bastian, former Chief of the Chesapeake Bay Model Branch, and Mr. T. E. Raster, Project Engineer for Acres American, Inc. Mr. T. E. Raster was also Test Engineer throughout the study for Acres American, Inc., Mr. M. A. Granat was Project Scientist for WES during the steady-state velocity tests, and Mr. L. G. Crosby was Project Engineer for WES during the dynamic salinity tests. Data analysis and preparation of the report were accomplished under the direct supervision of Mr. R. O. Bruno, Chief of the Chesapeake Bay Model Branch. Other key personnel involved in model testing were Messrs. H. J. Rhodes and N. W. Scheffner and Ms. V. R. Pankow for WES, and Messrs. W. M. Dyok and H. W. Whetzel for Acres American, Inc.

A preliminary boundary control and data presentation report was prepared by Mr. L. F. Gulbrandsen of Acres American, Inc., and was submitted by WES to NAB in March 1979. This present report was prepared by Mr. Granat with the assistance of Mr. Gulbrandsen.

Commanders and Directors of WES during the conduct of this study and the preparation and publication of this report were COL John L. Cannon, CE, COL Nelson P. Conover, CE, and COL Tilford C. Creel, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI)
UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
acres	0.4047	hectares
cubic feet per second	0.02831685	cubic metres per second
cubic yards	0.7645549	cubic metres
feet	0.3048	metres
feet per second	0.3048	metres per second
inches	25.4	millimetres
miles (U. S. statute)	1.609344	kilometres
square miles (U. S. statute)	2.589988	square kilometres

BALTIMORE HARBOR AND CHANNELS DEEPENING STUDY

Chesapeake Bay Hydraulic Model Investigation

PART I: INTRODUCTION

The Chesapeake Bay System and Baltimore Harbor

1. Chesapeake Bay, located on the east coast of the United States, is one of the largest, most productive, and diversely used estuaries in the world. The bay (Figure 1) extends approximately 190 miles* from the ocean entrance in the Commonwealth of Virginia, between Cape Henry and Cape Charles, to the Susquehanna River in the State of Maryland. In geologic terms, Chesapeake Bay is a submerged river valley and may be considered a dynamic remnant of the ancestral Susquehanna River. The average depth of the bay is about 28 ft; naturally deep areas greater than 50 ft traverse the bay for more than 60 percent of its length. The maximum depth of 175 ft is located near Bloody Point, Kent Island, Maryland, in the upper bay.

2. The bay is sufficiently long to accommodate one complete tidal wave at all times. Tides are semidiurnal and have low amplitudes, generally under 2 ft at most locations. The speed of the tidal wave allows a ship traversing up or down the bay to travel with favorable currents for most of its journey. In addition to the astronomical forces, meteorological and wind stress forces greatly influence the hydrodynamic characteristics of the estuary.

3. Like many coastal plain estuaries, the bay is irregular in shape varying in width from 4 to 30 miles. More than 64,000 square miles of drainage area empty into the partially mixed estuary. Five major western shore river systems (Susquehanna, Potomac, James, York, and Rappahannock) provide approximately 90 percent (over 61,000 cfs) of the mean

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* A table of factors for converting U. S. customary units of measurements to metric (SI) units is presented on page 4.

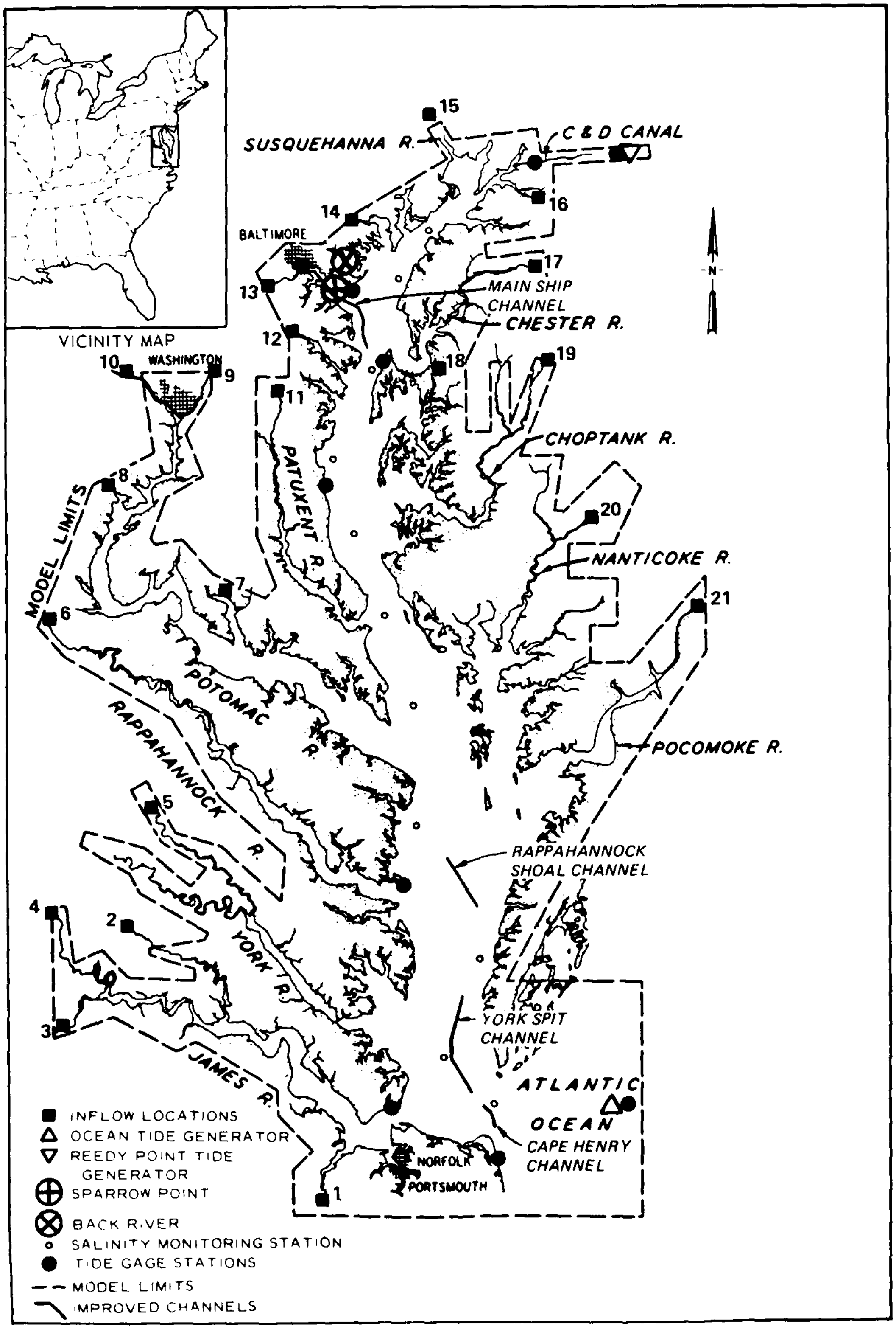

Figure 1. Location map for Chesapeake Bay

annual freshwater discharge. The Susquehanna River at the head of the bay contributes approximately one-half of the total bay freshwater inflow.

4. The interchange and mixing of fresh riverine water and salty ocean water within the estuary help maintain the Chesapeake Bay system as a productive natural resource. The many natural resources and processes within the bay, and man's activities in and on it, interact to form a complex and interrelated system. Man's continued development and utilization of these natural resources place increased stress on the system. Problems arise when man's intended use of one resource conflicts with either the natural environment or man's use of another resource. As a result of this incompatibility and the lack of knowledge of associated complex estuarine processes, a need exists for an overall bay management program. Through Section 312 of the Rivers and Harbors Act of 1965 (PL 89-298), Congress authorized the Corps of Engineers to construct, operate, and maintain a hydraulic model of Chesapeake Bay to assist in undertaking a complete investigation and study of water utilization and control of the Chesapeake Bay Basin.

5. This report covers the first major study conducted at the hydraulic model. Baltimore Harbor, in the Patapsco River, has historically ranked as one of the leading ports in the Nation and the world in terms of tonnage and dollar value. The Port of Baltimore is the closest North Atlantic port to the Midwest and is located close to the coal-rich areas of West Virginia, Ohio, and Pennsylvania. It is primarily a foreign trade port specializing in large, bulk-container cargo. Import of iron ore and export of coal are becoming especially important. With the continuing trend to larger and deeper draft vessels, water depth restrictions within Chesapeake Bay and Baltimore Harbor are making water transportation to and from Baltimore Harbor relatively inefficient.

The Improved Channels to Baltimore Harbor

6. Four reaches within Chesapeake Bay, as shown in Figure 1, constitute the 36.6 miles of improved navigation channels, maintained at a depth of 42 ft in the 172-mile journey from the Atlantic Ocean at

Cape Henry to Fort McHenry in Baltimore Harbor. These depths are presently inadequate to accommodate the existing larger size ships. Through Section 101, Public Law 91-611, of the 1970 Rivers and Harbors Act, Congress authorized a plan of improvement to deepen the existing channels and approaches to Baltimore Harbor to meet the existing and prospective needs of navigation.

7. The proposed plan of improvement calls for deepening the four reaches of improved channels from 42 ft to 50 ft and extending channels to the natural 50-ft-depth curves. These improvements will require dredging of over 70 million cu yd of material and will increase the total length of maintained channels by 13.7 miles, from 36.6 to 50.3 miles. The existing and proposed channel dimensions are listed below. Rappahannock Shoal channel is to be widened from 800 ft to 1000 ft. Additional improvements to several branch channels and anchorages within the Patapsco River have also been proposed.

	Existing		Proposed	
Channel	Length miles	Width ft	Length miles	Width ft
Cape Henry	1.0	1000	2.3	1000
York Spit	10.4	1000	18.2	1000
Rappahannock Shoal	5.3	800	9.9	1000
Main Ship (Baltimore Harbor and approach)	19.9	800	19.9	800

Test Objectives

8. Tests using the Chesapeake Bay hydraulic model were undertaken to investigate possible changes to the hydrodynamic characteristics of velocity, salinity, and tidal elevations of the system due to the proposed channel enlargements.

The Chesapeake Bay Hydraulic Model

9. Briefly, the fixed-bed model is molded in concrete to conform to the most recent bathymetry at the time of construction (1974). The

8.6-acre model is housed in a 14-acre shelter approximately 1000 ft long and 600 ft wide for protection from the elements. The molded area of the model extends to the +20 ft contour from the offshore Atlantic Ocean to the head of tide for all tributaries emptying into Chesapeake Bay. Economics and hydrodynamics were considered in choosing the 1:1000 horizontal and 1:100 vertical model to prototype scales. Time (1:100), velocity (1:10), and discharge (1:1,000,000) scales are based on Froudian scaling laws reflecting similitude of gravitational effects. Salinity is maintained at a 1:1 ratio.

10. The model was designed to include all necessary appurtenances for the accurate reproduction and measurement of prototype conditions. It differs somewhat from most other physical models in size and degree of automation. Both freshwater inflows and tide generators can be completely computer-controlled. Inflows are computer-controlled through a feedback mechanism that allows accurate control of variable discharges from drought to hurricane conditions. Any desired hydrograph can be programmed for each of the 21 inflow points on the model (Figure 1). For site-specific studies, watersheds can be further subdivided to additional inflow points. The two tide generators (ocean and Chesapeake and Delaware (C&D) Canal, Figure 1) are computer-controlled and are capable of simulating any desired tide sequence including a lunar month of variable tides producing neap to spring variations.

11. As in other distorted-scale physical models, stainless steel roughness strips projecting from the model bottom are used to adjust flow patterns and serve to increase the frictional resistance and, to some extent, the degree of vertical mixing. An induced-mixing bubble line of compressed air, from the model bottom running along the axis of the bay and major tributaries (Figure 2), is utilized in reducing the degree of stratification resulting from the lack of meteorological mixing in the model. This system has been improved from the tygon tubing used during verification to a 1/2-in. ID copper tubing supply line above the water level, feeding air through stopcock valves to 1/8-in. ID copper tubing drop lines to the model bottom (Figure 3). These drop lines, at about a 12-ft spacing, provide a bubbling grid similar to verification

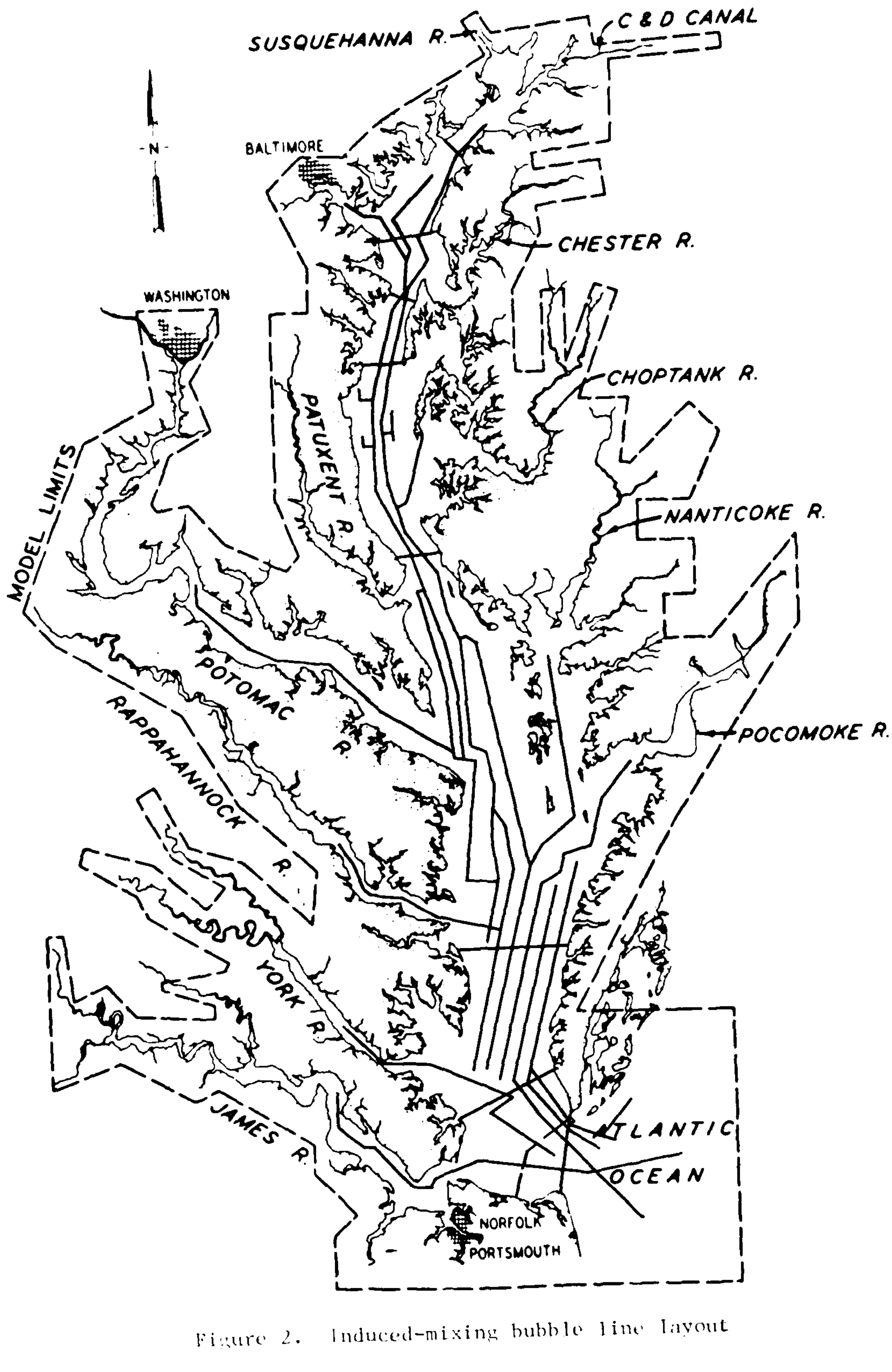

Figure 2. Induced-mixing bubble line layout

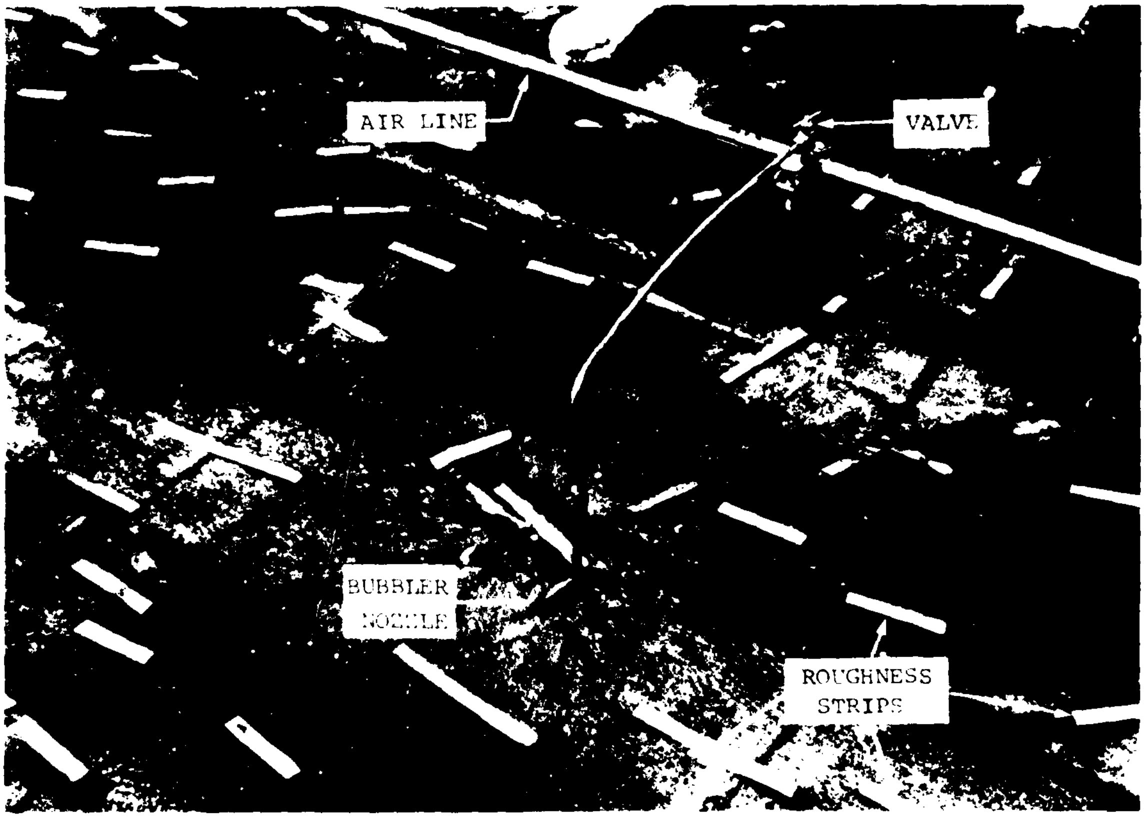

Figure 3. Induced-mixing bubble line drop

conditions, with an extension into the Patapsco River. A detailed description and discussion of all additional model appurtenances and model verification are presented in a separate report (Scheffner et al. 1981).*

Scope of Model Tests

12. Tests were performed with the hydraulic model to assess the magnitude of variations in velocity, salinity, and tidal characteristics associated with the proposed improvements to the Baltimore Harbor and

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* N. W. Scheffner et al. 1981 (Dec). "Verification of Chesapeake Bay Model; Chesapeake Bay Hydraulic Model Investigation," Technical Report HL-81-14, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Channels area. A series of base tests were conducted using the verified model with the existing 42-ft channels plus a 2-ft dredging tolerance. After these tests were completed, the channels were remolded to the new authorized 50-ft depths plus a 2-ft dredging tolerance, and a series of compatible plan tests were similarly performed. Roughness strip distribution determined during model verification was maintained. A similar distribution was reestablished in the deepened channel areas for the plan tests. The induced-mixing bubble line was similarly maintained with appropriate extension to the model bottom, where necessary, for the plan test.

13. Two separate modes of model operation and testing were followed. In the first mode velocity measurements were undertaken at 13 selected stations during four separate steady-state tests utilizing fixed boundary conditions. In the second mode salinity and tide-height measurements were collected at 68 and 10 locations, respectively, during dynamic conditions associated with a repetitive 28-lunar-day variable tide sequence and a 2-1/2-year freshwater discharge hydrograph which was stepped weekly (solar time). These two operating and testing modes will be discussed separately in the following sections.

PART II: STEADY-STATE VELOCITY TESTING

Test Conditions

14. Steady-state velocity tests were designed to examine variations covering a wide range of specific fixed boundary conditions. For each test a cosine tide with either a neap (2.55 ft) or spring (3.75 ft) range was repeatedly generated from the ocean tide generator. The other boundary control test parameter that changed from test to test was freshwater discharge. The long-term average flow distribution for each of the 21 inflow points (proportion of total bay discharge as determined by the U. S. Army Engineer District, Baltimore) was maintained; however, the total bay discharge was selected as either 30,000 cfs representing a seasonal low-flow period or 120,000 cfs representing a seasonal high-flow period. Table 1 presents the long-term average flow distribution (percentage) and the specific flows for each inflow device. A different combination of tide and discharge (i.e. spring tide 120,000 cfs; neap tide 120,000 cfs; spring tide 30,000 cfs; and neap tide 30,000 cfs) was utilized for each of the four steady-state tests.

15. The following boundary conditions were maintained during all tests. A cosine tide was generated at the Delaware end of the C&D Canal to achieve the mean tide range of 2.75 ft at Chesapeake City (sta 75). The tide plane was adjusted to maintain a zero net flow of water through the C&D Canal. C&D Canal source salinity (Delaware Bay) was allowed to vary between 2 and 5 ppt before adjustments were made at the Reedy Point end of the canal. Ocean source salinity was maintained at approximately 32.5 ppt. Two sources of industrial discharge were also simulated in the model study. The long-term average discharge for the Sparrows Point Steel Manufacturing Plant in the Patapsco River (186 cfs) and the Back River Sewage Treatment Plant (58 cfs) were added to the model at their respective locations (Figure 1). Model boundary control during all tests was considered acceptable. A complete documentation of all

boundary conditions is available (Gulbrandsen 1979).*

Test Data and Results

16. Once appropriate boundary conditions were established salinity monitoring was begun at 11 salinity monitoring stations (Figure 1) to assess when a stable salinity distribution (the same salinity profile from one tidal cycle to another) was reached. Once a relative stability was achieved, velocity measurements were taken at the 13 designated velocity stations (Figure 4) for bottom, middle, and then surface depths. Seven of the thirteen stations were within the dredged channels (CPH-1, CB-1-5, YSC-4, RSC-2, CC-2, BC-4, and FM-1), four stations were positioned in potential dredged material disposal areas (OD-1, OD-2, OD-3, and OD-4), and two stations were located adjacent to channels to be deepened (YSC-1 and BC-2). Sampling depths at the seven deepened channel stations were adjusted for the plan test to maintain the same relative sampling depths within the water column. Table 2 provides sampling depths for each station.

17. Miniature Price-type mechanical cup wheel current meters (Figure 5) were utilized at 11 stations (excluding the two upper Patapsco River sta BC-4 and FM-1). The number of revolutions in a 10-sec interval (real time) was recorded every 36 sec (1 hr prototype) for 15 min to obtain a complete day's velocity record at each desired depth. The accuracy of these measurements is generally between 0.25 and 0.50 fps (prototype). The accuracy increases with increased current speed. A least-squares cosine curve fitting program with an M_2 (tidal harmonic constituent) frequency was employed to obtain summary values of phase, amplitude, and offset. The fitted curve is of the form:

$$y = h_o + a \cos (\theta_{m_2} + \phi)$$

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* L. F. Gulbrandsen. 1979. "Baltimore Harbor and Channels Deepening Study; Hydraulic Model Boundary Control and Data Presentation," Acres American, Inc.; report on file at U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss., and U. S. Army Engineer District, Baltimore, Baltimore, Md.

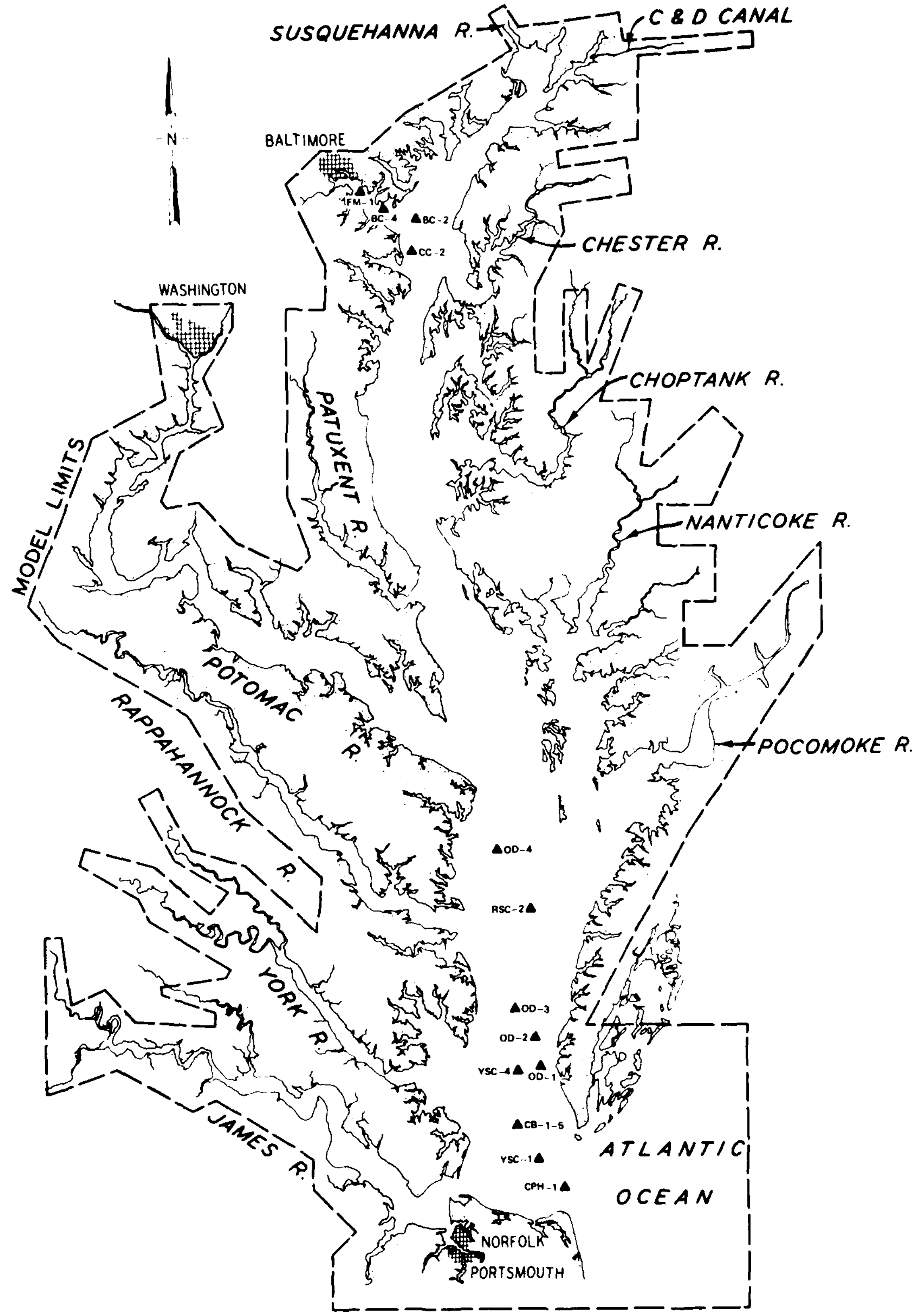

Figure 4. Velocity sampling station location map

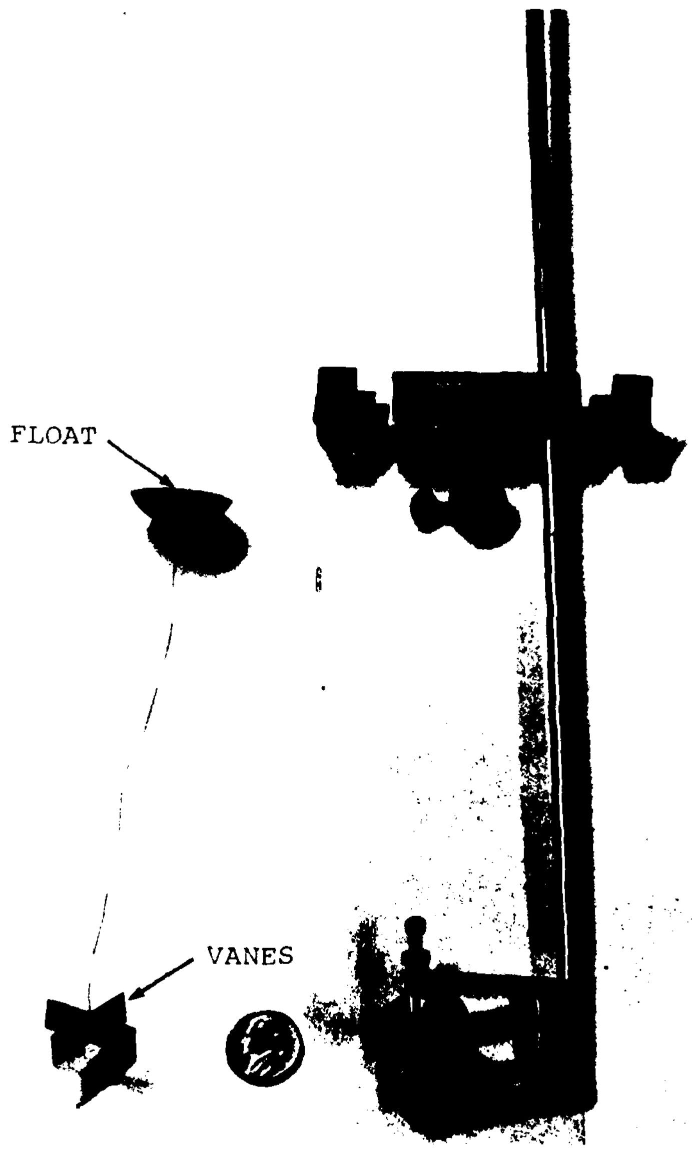

Figure 5. Drogue and miniature Price-type current meters

where:

h_o = offset and indicates flood dominance when positive, ebb dominance when negative

a = amplitude, one half the height of the cosine curve

θ_{m_2} = the M_2 tidal harmonic constituent

ϕ = the phase angle; time of peak velocity in degrees, approximately 29 deg/hr.

Confidence in these obtained values is generally greater than that in observed values since all measurements are together taken into consideration, with anomalous values having little influence.

18. A miniature drogue and float device (Figure 5) was used at the two upper Patapsco River stations (BC-4 and FM-1) since their velocities were generally of insufficient magnitude to overcome threshold of movement of the mechanical cup wheels. This measuring technique employed a stopwatch; a circular ring stand with an inner and outer circle (inner circle diameter 0.25 ft, outer circle radius from edge of inner circle 0.50 ft); and a flotation device constructed from a half sphere of cork (diameter 0.1 ft), a plastic cross (each arm of cross 0.4 in. high by 0.7 in. long), and a wire which connected the cork and cross (length varied according to desired depth, Table 2). The center of the ring stand was placed over the desired station. At the designated hour the flotation device was released from the center of the station, and time of travel from the edge of the inner circle to the outer circle, a distance of 0.50 ft, was recorded. This procedure was repeated for each hour to obtain a complete day's record.

19. Several difficulties were encountered during these Lagrangian measurements. Roughness strips and channel walls frequently interfered with the drogue movement. In some cases, water flow was so slow that measurements continued beyond a 36-sec interval (1 hr prototype) or were not completed due to slack water or current reversals. Measurements were reduced to hourly velocity values and analyzed with the least squares cosine curve fitting program. The nature of this program requires that missing hourly data be assigned zero values. Due to the unfamiliar technique, the sluggish velocities, and their associated

characteristics, the error band of drogue measurements is difficult to assess but is probably close to 0.2 fps (prototype). Many of the observed velocities are within this error band. An alternative technique employing droplets of neutrally buoyant oil as the tracking medium proved even more difficult and inefficient.

20. Plates 1-26 illustrate observed velocities and the cosine fit for compatible base and plan conditions for all stations and tests. Associated phase, amplitude, and offset values are presented in Tables 3-6. Maximum flood (amplitude + offset) and maximum ebb (amplitude - offset) values are also provided. Base and plan plots of phase, amplitude, and offset values as functions of depth for all stations during each test are illustrated in Plates 27-30. Tables 7-10 present plan minus base differences for phase, amplitude, offset, maximum flood, and maximum ebb values for each test. Plate 31 illustrates plots of phase, amplitude, and offset differences as functions of depth. Plate 32 illustrates plots of maximum flood and maximum ebb differences as functions of depth for each test. Frequency-of-occurrence tables provide a final summary (total of all tests) of plan-to-base differences for each of the velocity attributes (Tables 11-15).

Discussion of Results

21. The least-squares cosine curve fitting program provides an excellent basis for evaluating the velocity measurements; however, since this is a smoothing technique, consideration should also be given to the hourly values and station locations to ensure accurate and complete interpretations. By curve fitting, all hourly observations are together taken into consideration in obtaining the three summary values (phase, amplitude, and offset) that are generally insensitive to a few outlier observations. The obtained values therefore have a higher confidence than individual observations.

22. Sta YSC-1 (Plates 3 and 4), located immediately north of one of the Chesapeake Bay Bridge-Tunnel islands, is affected by local turbulence, eddies, and constriction caused by the island creating anomalies

to the true flow characteristics associated with channel deepening. Data from this station must be viewed with reservation. Indicated variations at sta FM-1 (Plates 25 and 26), in upper Baltimore Harbor, must also be viewed cautiously. Velocities at this station were generally lower than the error band of the measurements. At such low velocities, phase values are especially sensitive to erroneously high values. Low velocities also prevail at other stations; thus phase values should not be considered at sta FM-1, the bottom depth at sta OD-4 during both neap tide tests, middle and bottom depths at sta BC-2 during all four tests, and middle and bottom depths at sta BC-4 during the 30,000-cfs neap tide test.

23. Over 75 percent of the remaining 132 observations (Plate 31 and Table 11) had base and plan phase values within 10 deg of one another (approximately 20 min prototype time, close to the confidence of this measurement). The largest phase variations were found at RSC-2 and OD-4 during the 120,000-cfs spring tide test (Plate 31). Time of maximum velocity during the plan test occurred up to 66 deg later than during the base test (over 2 prototype hours or 72 real seconds). Isolated variations of this type and of this magnitude are difficult to understand and no logical explanation can be provided after a thorough review of raw data and boundary control reports. Sta BC-4 was the only other station to indicate phase differences greater than ±30 deg. These differences may be the result of errors associated with the drogue measurements. Later arrival time for the plan test again occurred during the larger discharge spring test. The larger discharge neap test and lower discharge spring test indicated earlier times of occurrence for the plan tests compared with the base tests at this station. Earlier times of maximum velocity for the plan test also occurred at sta CC-2 during the larger discharge neap tide test.

24. In general, the fitted cosine curve approximates observed velocities to a reasonable degree. At sta YSC-1, however, the observed peak flood velocities are generally underestimated (Plates 3 and 4). Variations between the fitted peak velocity and the observed velocity are greatest during the plan tests, especially during the larger range tide. These perturbations from the ideal cosine can be attributed to

constriction and/or eddy effects associated with the Bay Bridge island.

25. Only subtle differences were indicated for plan-to-base comparisons of amplitude, offset, maximum flood, and maximum ebb values (Plates 31 and 32). Over 90 percent of these comparisons for each of the parameters were within ±0.40 fps, the error band for these measurements.

26. Amplitude values provide an indication of total water flow in the immediate vicinity of each measurement point (half the range between peak fitted velocities) without regard to flow dominance. Largest amplitude variations were at sta YSC-1 during the spring tide tests (Tables 7-10); measurements at bottom depths indicated larger velocities during the plan test, around 0.50 fps greater, while plan surface measurements were up to 0.60 fps less than those of the base test. Overall, 96 percent of all amplitude comparisons were within ±0.40 fps, 86 percent were within ±0.25 fps, and 47 percent were within ±0.10 fps (Table 12). A general tendency of lower amplitudes during the plan tests was indicated. This meets expectations of lower velocities associated with channel deepening and increased crosssectional area.

27. Offset values provide an indication of flow dominance. Care must be used in the interpretation of this parameter. For example, an increase in flood dominance may be the result of either an increased flood (duration or amplitude) or a decreased ebb or a combination of both. Over 97 percent of all plan offset values were within ±0.40 fps of comparative base values, 92 percent of the values were within ±0.25 fps, and 66 percent of the observations were within ±0.10 fps (Table 13). A general trend of slightly increased flood dominance (between 0.10 and 0.25 fps) was indicated for lower bay stations (below the Potomac River). Upper bay stations generally showed little (±0.10 fps) offset variations between base and plan tests.

28. Offset and amplitude values were combined to obtain maximum ebb and maximum flood fitted velocities (Plate 32) to ascertain which of the above scenarios exist. Over 90 percent of plan maximum flood and maximum ebb velocities were within ±0.40 fps of base velocities, around 77 percent were within ±0.25 fps, and over 42 percent were within

±0.10 fps (Tables 14 and 15). In general, flood velocities increased for lower bay stations but decreased for upper bay stations when comparing plan tests with base tests. Plan test ebb velocities throughout the estuary indicated a general trend of reduced velocity compared with base tests.

29. In summary, no major velocity variations were indicated as a result of channel deepening; however, slight trends in velocity characteristics may indicate subtle variations in the hydrodynamics of the system. The overall reduced velocity (amplitude) at each depth during the plan tests is consistent with increased cross-sectional area associated with channel deepening. The slight trend of increased flood dominance (higher flood and lower ebb velocities) at the lower bay stations indicates the possibility of additional salt intrusion into the main estuary along the deepened channel. A return flow of estuarine water may exist in the shallower nonsampled areas.

PART III: DYNAMIC SALINITY AND TIDE-HEIGHT TESTING

Test Conditions

30. Salinity and tide-height testing was designed to examine plan-to-base variations during naturally occurring dynamic conditions associated with a repetitive 28-lunar-day (56 cycle) variable tide sequence and a 2-1/2-year freshwater discharge hydrograph stepped weekly. Constant steady-state boundary conditions used during the prelead-in portion of the base and plan tests include an ocean repetitive cosine tide with a 4.25-ft range, a 5.90-ft range C&D Canal repetitive cosine tide with a zero net flow plane, and a 150,000-cfs total bay freshwater discharge. Ocean source salinity was maintained at 32.5 ppt throughout each test while the C&D Canal source salinity (Reedy Point) was allowed to vary between 2 and 5 ppt before adjustments were made. The computer-controlled dynamic portion of each test was begun once a relatively stable salinity distribution was observed at the 11 salinity monitoring stations. The total bay freshwater discharge hydrograph for this 2-1/2-year dynamic period is presented in Table 16 and illustrated by Figure 6. Similar information is available for each inflow location (Gulbrandsen 1979).*

Inflows

31. Hydrograph conditions simulated prototype weekly average freshwater discharges for each inflow location from April 1964 (hydrograph step 1) through September 1965 (hydrograph step 77), a relatively low-flow or drought period, followed by a smooth, synthesized "average" or "modal" year hydrograph provided by the Baltimore District. Due to inability to measure extremely low discharges (below 74 cfs prototype), flows associated with inflow locations 2 and 3 were added through inflow 4, inflow 9 was added to inflow 10, and flows associated with inflow 18 were discharged through inflow 19. A computer failure during the base test in the middle of the modal year hydrograph (lunar day 711,

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* Gulbrandsen, op. cit.

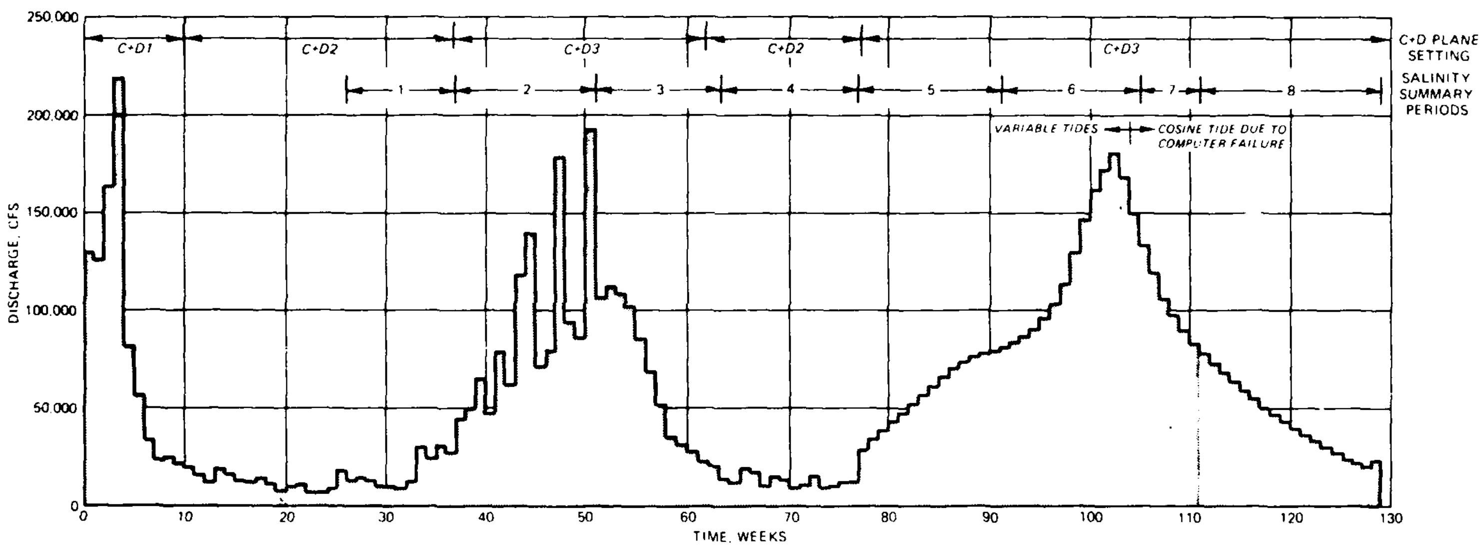

Figure 6. Total bay freshwater discharge hydrograph. C&D plane settings determined during the following steady-state Susquehanna discharge conditions: C&D No. 1 setting for 52,000 cfs; C&D No. 2 setting for 5,000 cfs; C&D No. 3 setting for 38,000 cfs; prelead-in setting for 80,000 cfs. See text for explanation

hydrograph step 106) required manual inflow settings for the remainder of the test. A similar procedure was followed during the plan test to ensure compatible conditions. As in velocity testing, the long-term average discharges for Sparrows Point Steel Manufacturing Plant (186 cfs) and Back River Sewage Treatment Plant (58 cfs) were continuously added to the model during both base and plan tests.

Tides

32. The reconstructed, 12-constituent, 28-lunar-day source tide repeatedly generated from the ocean tide generator during the dynamic testing portion is illustrated in Figure 7. As shown, this tidal sequence includes two spring tides, a high spring and a low spring, and two approximately equal neap tides. The compatible 5-constituent, 28-lunar-day source tide generated concurrently from the C&D Canal tide generator is illustrated in Figure 8. After loss of computer control during the base test at lunar day 711, repetitive cosine tides were established at the ocean and C&D Canal (4.25-ft range and 5.90-ft range, respectively) and maintained throughout the remainder of the test. A similar failure was simulated and procedure followed during the plan test.

33. A long-term zero net flow condition for the C&D Canal was desired. Flow through the canal is influenced by, and is sensitive to, differences in water level elevations between both ends of the canal, caused by such factors as Susquehanna discharge and meteorological events. Four separate Susquehanna discharges (80,000, 52,000, 38,000 and 5,000 cfs) were used during preliminary steady-state cosine tide control operation to determine the required C&D Canal tide plane needed to achieve the desired zero net flow for each discharge condition. It was felt that this cosine tide could be used to approximate average discharge conditions of the 28-lunar-day tide. These established plane adjustments were used during the indicated periods of the hydrograph (Figure 6) in an attempt to achieve the desired long-term zero net flow condition, without risking incompatible base and plan tests, due to boundary control differences associated with unscheduled plane adjustments.

Performance

34. A complete documentation of all boundary controls during these

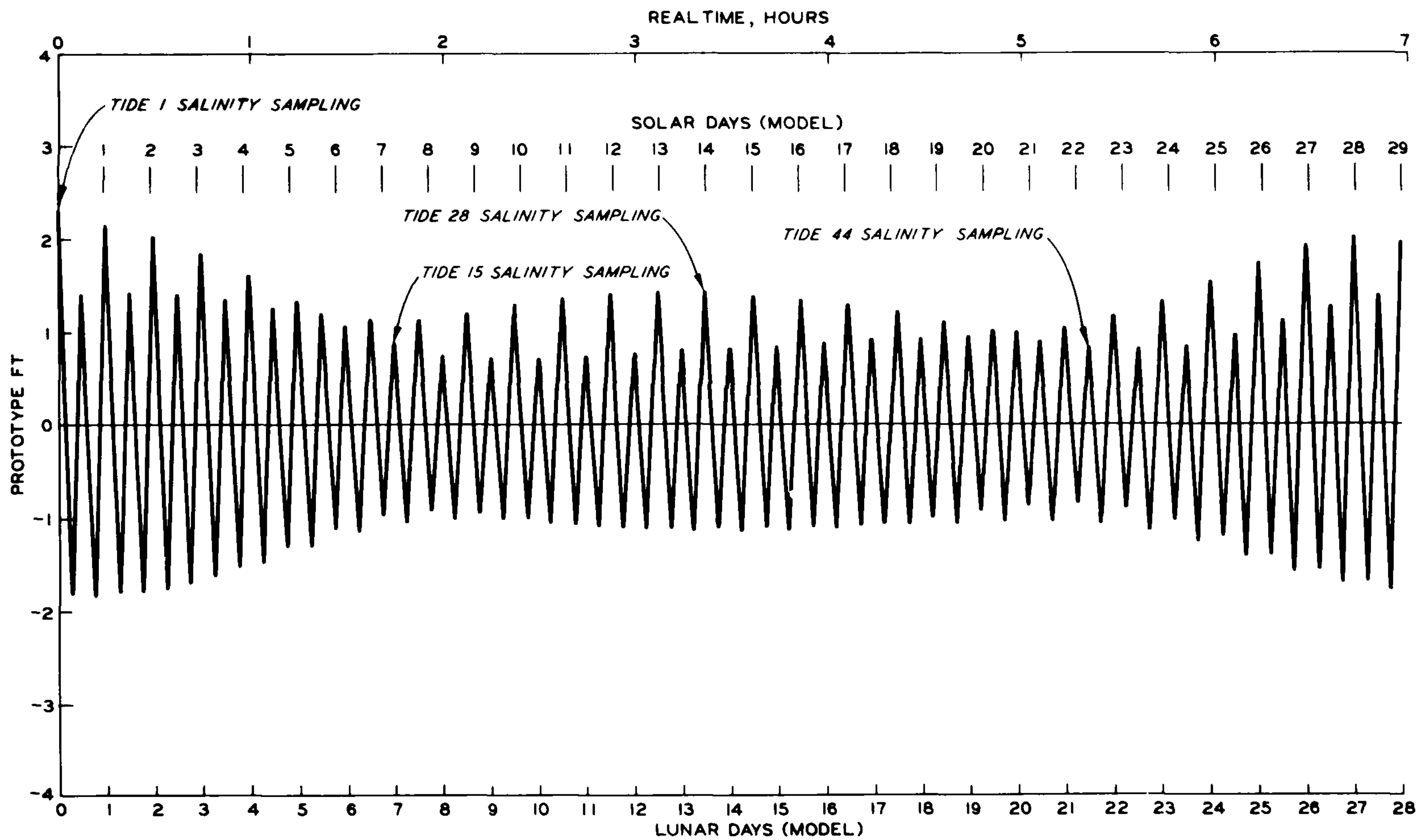

Figure 7. Twelve constituent, 28-lunar-day, ocean source tide

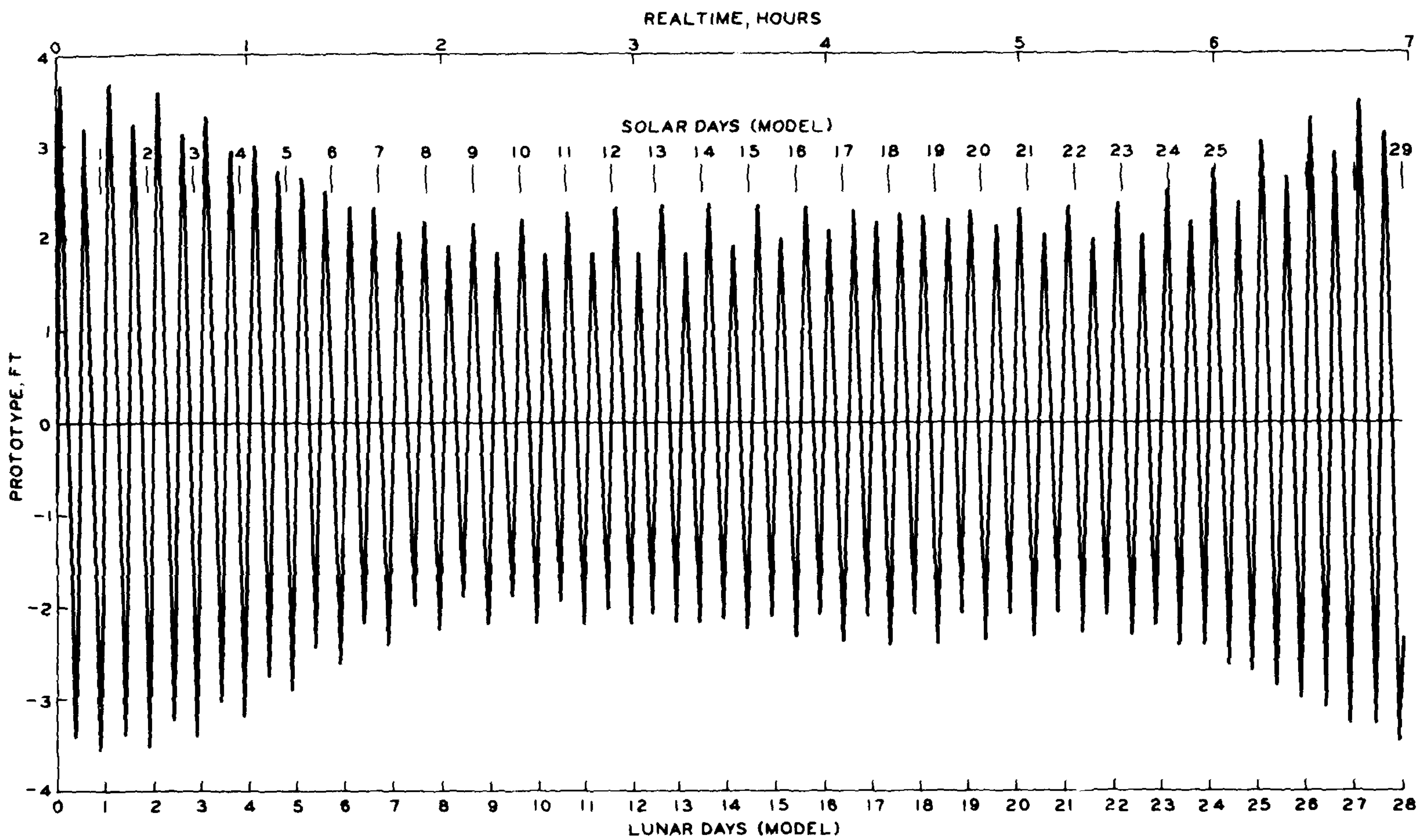

Figure 8. Five constituent, 28-lunar-day, C&D Canal source tide

tests is available (Gulbrandsen 1979).* Although the following perturbations did occur between base and plan tests, overall boundary control was considered acceptable, with little or no indicated impacts to final test results. Variations in C&D Canal net flows produced no significant impacts on major test findings. Peristaltic pumps and tubing used at the Sparrow Point and Back River effluent discharge points proved inefficient and required frequent adjustment, however, the variations in these flows are felt to be insignificant to test results. Discharge variations from the regular inflow devices are also thought to have minimal impact to test results. Despite improvements to the induced-mixing bubble line, bubble rate tended to decay with time due to formation of salt deposits at the air-water interface. Information to assess impacts on salinity during these tests is not available; however, tests performed at the model (spring 1980) indicate that salinity characteristics are relatively insensitive to variations in bubble rate.

Test Data and Results

Tides

35. Ten automatic water-level detectors were located at key stations throughout the model (Figure 1). Water-level elevations were recorded at hourly prototype intervals (every 36 sec, real time) and stored on flexible diskettes. Manual point gage measurements were not taken. Analysis of this information, after testing was completed, indicated several unforeseen difficulties. Condensation on probe face plates caused the probe to rise above the desired distance from the water's surface and resulted in apparent drifting tidal planes. Sensitivity adjustments to probes, to overcome problems of interference from surface waves caused by the induced-mixing air bubbles, created additional problems of truncation to either peaks or troughs of measurements at variable frequencies. These adjustments also increased the error band width of the measurement. In most cases, associated errors are random and uncorrectable. For

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* Gulbrandsen, op. cit.

these reasons, obtained tidal data were considered unreliable and no additional analyses were performed.

Salinities

36. Salinity monitoring stations were sampled during all aspects of base and plan testing for assessment of stability during pre-lead-in and for sampling conformity with previous and future testing. Salinity values for the salinity monitoring stations are available at the model in the form of tables and plots, however, due to their low sampling priority (boundary control and test sampling had priority), many gaps exist between base and plan values. Salinity sampling at the 68 designated test stations (Figure 9) began on lunar day 168, following 6 months of dynamic lead-in conditions (hydrograph steps 1-25 from April through September 1964 and repetitive 28-lunar-day tide). Slack-after-flood samples were collected at approximately weekly intervals, corresponding to spring and neap tidal cycles, throughout the remaining portions of each test. Figure 7 illustrates the sampling schedule for a typical 28-lunar-day sequence. Tides 1, 15, 28, and 44 of each 56-cycle sequence were sampled. This schedule was continued during cosine tide generation following the computer failure. To obtain ranges of salinity, slack-after-ebb samples were collected following slack-after-flood sampling four times during both water year 1965 and the modal water year. These data are tabulated and available (Gulbrandsen 1979).*

37. Stations were sampled at two to five depths, depending on local water depths. Bottom sampling depths were adjusted accordingly, to maintain same relative sampling depth, for the plan test at those stations located in areas of bathymetric change. All other sampling points remained in place. Sta FM-1 (in the Patapsco River) was relocated from PR-3-1 at lunar day 647 during both base and plan tests. Station and sampling depths are presented in a relative geographical order, from lower bay or system to upper bay or system in Table 17. In the Patapsco River area, stations within the main ship channel are first presented in an up-channel order, followed by stations in side channels and adjacent

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* Gulbrandsen, op. cit.

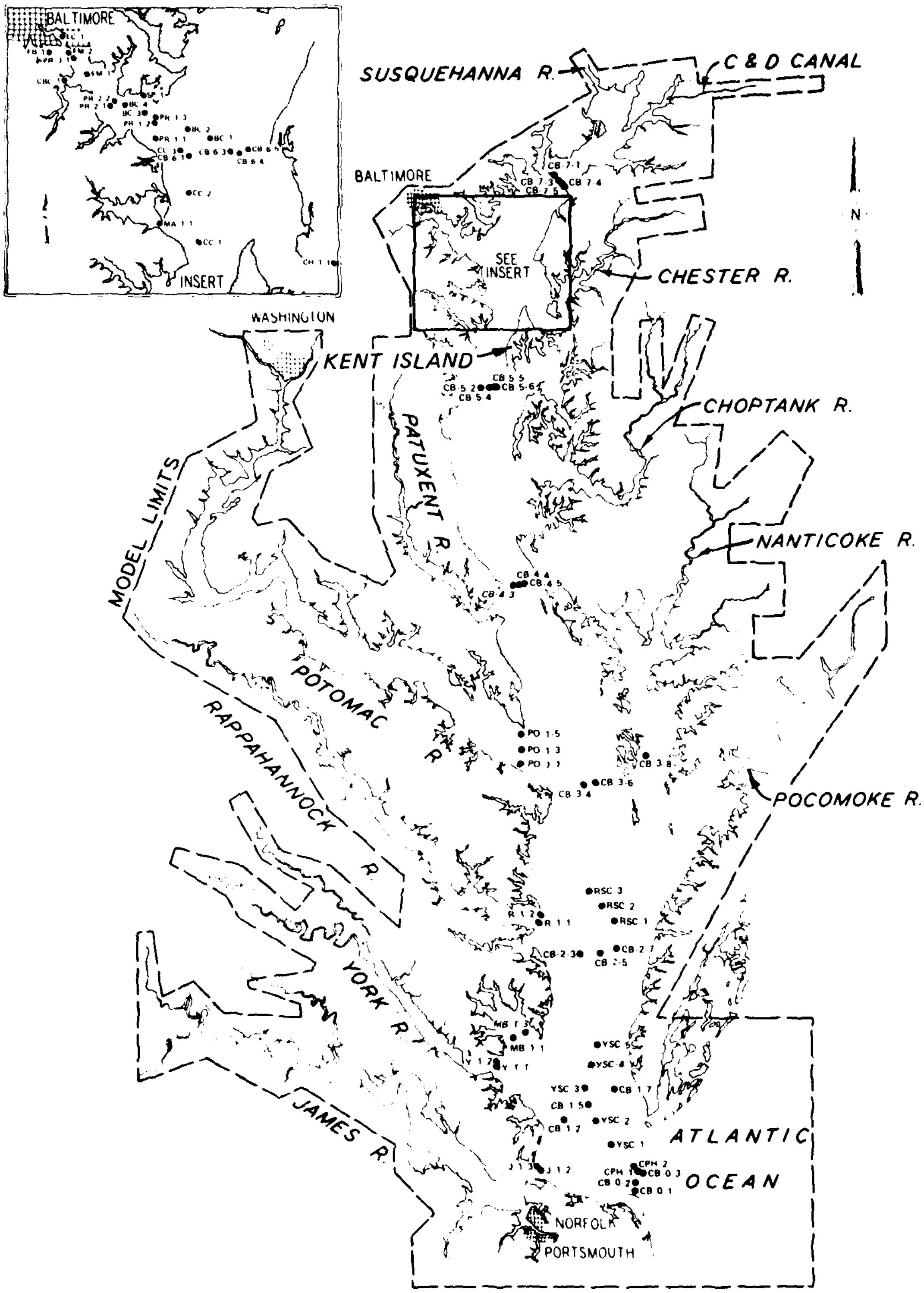

Figure 9. Salinity sampling station location map

areas in a downriver order. This station order is maintained throughout the remaining portions of this report.

38. Separate base, plan, and plan minus base time-history salinity plots are illustrated for each of the 68 stations in Plates 33-100. Based on presented data, experience, and laboratory experiments, each individual salinity measurement during this study is generally felt to be accurate within 0.5 to 1.0 ppt. A ±2 ppt interval is indicated on each time-history salinity difference plot to aid in interpretation of the data. Tables listing each of the salinity values by lunar day are available (Gulbrandsen 1979).*

39. For summary purposes, the two years of salinity testing were divided into the following eight convenient periods based upon natural variations in freshwater discharge:

Period	Hydrograph Steps, Weeks	Lunar Days
1	26-37	168-249
2	38-51	249-344
3	52-63	344-425
4	64-77	425-520
5	78-91	520-615
6	92-105	615-709
7	106-111	709-750
8	112-129	750-871

Period 1 corresponds to the prototype low-flow period October through December 1964, period 2 corresponds to the increasing discharge period January through March 1965, period 3 represents the decreasing flow period from April through June 1965, and period 4 represents the low flow period July through September 1965. The modal water year was also divided into four periods. Period 5 represents the first 14 weeks of increasing freshwater discharge; period 6 represents the next 14 week period of higher discharges, the last two weeks of which were of

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* Gulbrandsen, op. cit.

decreasing discharge although still greater than 150,000 cfs; period 7 corresponds to the loss of tide control and the following 6-week period during a falling discharge; and period 8 corresponds to the remaining 18 weeks of modal year discharge under cosine control (also a falling discharge period). These eight periods are indicated in Figure 6.

40. Frequency-of-occurrence tables were prepared to provide a detailed station by station summary of plan minus base salinity differences for each period. These tables are not included in this report, but are on file at CBM, WES, and NAB. The number of salinity difference values occurring within each of the following 11 intervals is tabulated for surface, middle, and bottom depths:

Values less than -10 ppt
$-10 \le$ values < -5
$-5 \le$ values < -3
$-3 \le$ values < -2
$-2 \le$ values < -1
$-1 \le$ values ≤ 1
$1 <$ values ≤ 2
$2 <$ values ≤ 3
$3 <$ values ≤ 5
$5 \le$ values ≤ 10 and
Values greater than +10 ppt

41. Table 18 provides a final combined summary of salinity variations occurring during the variable tide portion of the test (periods 1-6) for each station at surface, middle, and bottom depths. Percent frequency-of-occurrence values within each salinity difference interval are presented in this table. Figure 10 graphically summarizes for each station at surface, middle, and bottom depths the percent frequency of occurrence of plan minus base salinity differences greater than ±2 ppt.

Discussion of Results

42. Time-history plots (Plates 33-100) illustrate various salinity trends at each of the 68 stations. Three basic trends in base and plan salinity time-histories are considered to provide a basis for

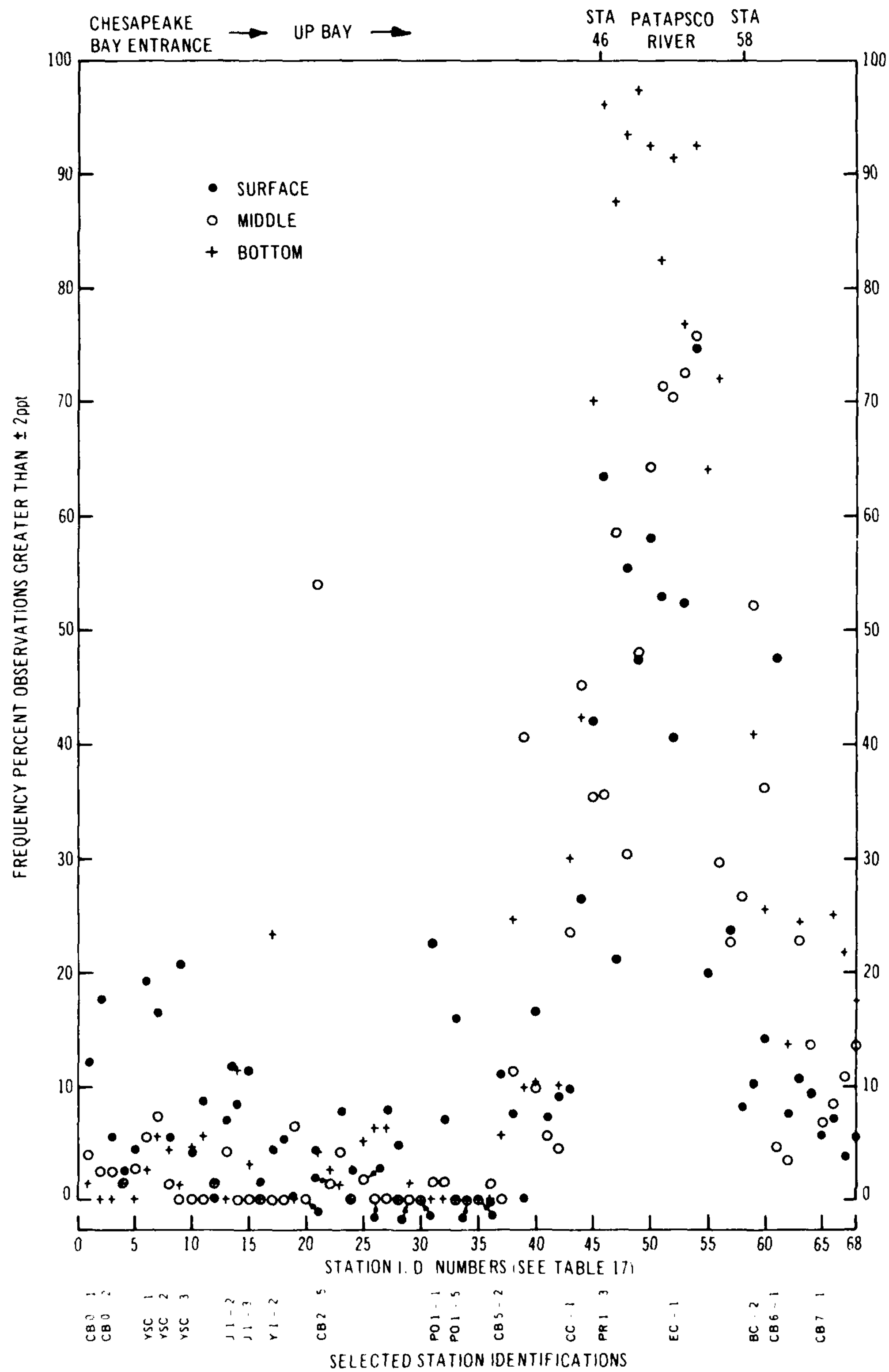


Figure 10. Percent frequency of occurrence of plan minus base salinity differences greater than ± 2 ppt. See Table 17 for additional station identifications

comparing base versus plan results. The dominant underlying trend at most stations is an inverse relationship between freshwater discharge and salinity concentration--as discharge increases salinity decreases. Surface layers show greatest sensitivity to freshwater discharge with largest salinity changes over time. This sensitivity generally decreases toward the ocean entrance and with increasing water depth. Deeper depths in the lower bay, for example, are somewhat insensitive to freshwater discharge variations.

43. In addition to this discharge response, a superimposed shorter frequency response is indicated at many stations. This salinity response is associated with neap-spring tidal cycle variability, producing a sawtooth pattern in time-history salinity plots. Lower bay stations, below the main bay constriction at range CB-4 (Figure 9), generally appear to be more sensitive to this tidal response characteristic with neap-spring salinity variations increasing with approach to the ocean entrance and with increasing depth below the surface. Bottom depths at the three stations sampled along the entrance range (CB-0-1, CB-0-2, and CB-0-3) and the adjacent two Cape Henry Channel sta CPH-1 and CPH-2, however, show smaller salinity variations (about 1 ppt) while surface measurements show greatest responses (Plates 33, 34, 35, 36, and 37, respectively). Bottom depths at these stations show reduced sensitivity to tidal cycle variations due to their closeness to the ocean boundary. Some of the largest tidal cycle variations occur at sta CB-0-2, where neap-spring surface salinity variations up to 7 ppt are indicated. Figure 11 (from Plate 34) illustrates the plan test time-history salinity plot with appropriate monthly tide ($spring_1$, $neap_1$, $spring_2$, or $neap_2$) labeled for surface samples.

44. In the lower bay tributaries sampled, the two James River stations illustrate the greatest tidal sensitivity, greater than any other stations sampled in the model. Figure 12 (from Plate 47) illustrates the plan test salinity time history for sta J-1-3. Sta Y-1-2 (Plate 49), in the entrance to the York River, indicates large salinity variations only during the base test. York River sta Y-1-1, Mobjack Bay sta MB-1-1 and MB-1-3, Rappahannock River sta R-1-1 and R-1-2, and Potomac River

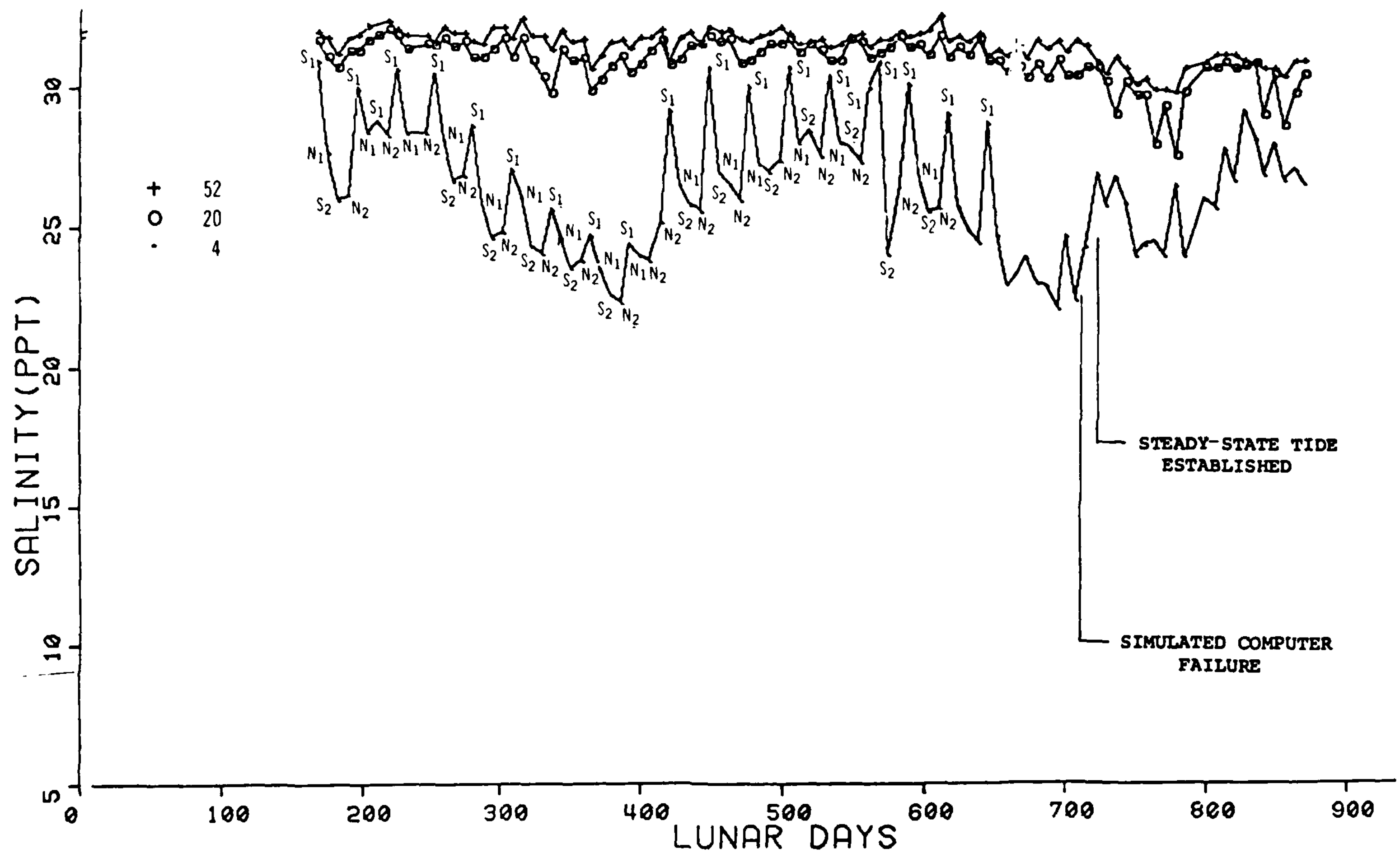


Figure 11. Station CB-0-2 plan test salinity time-history (from Plate 34)

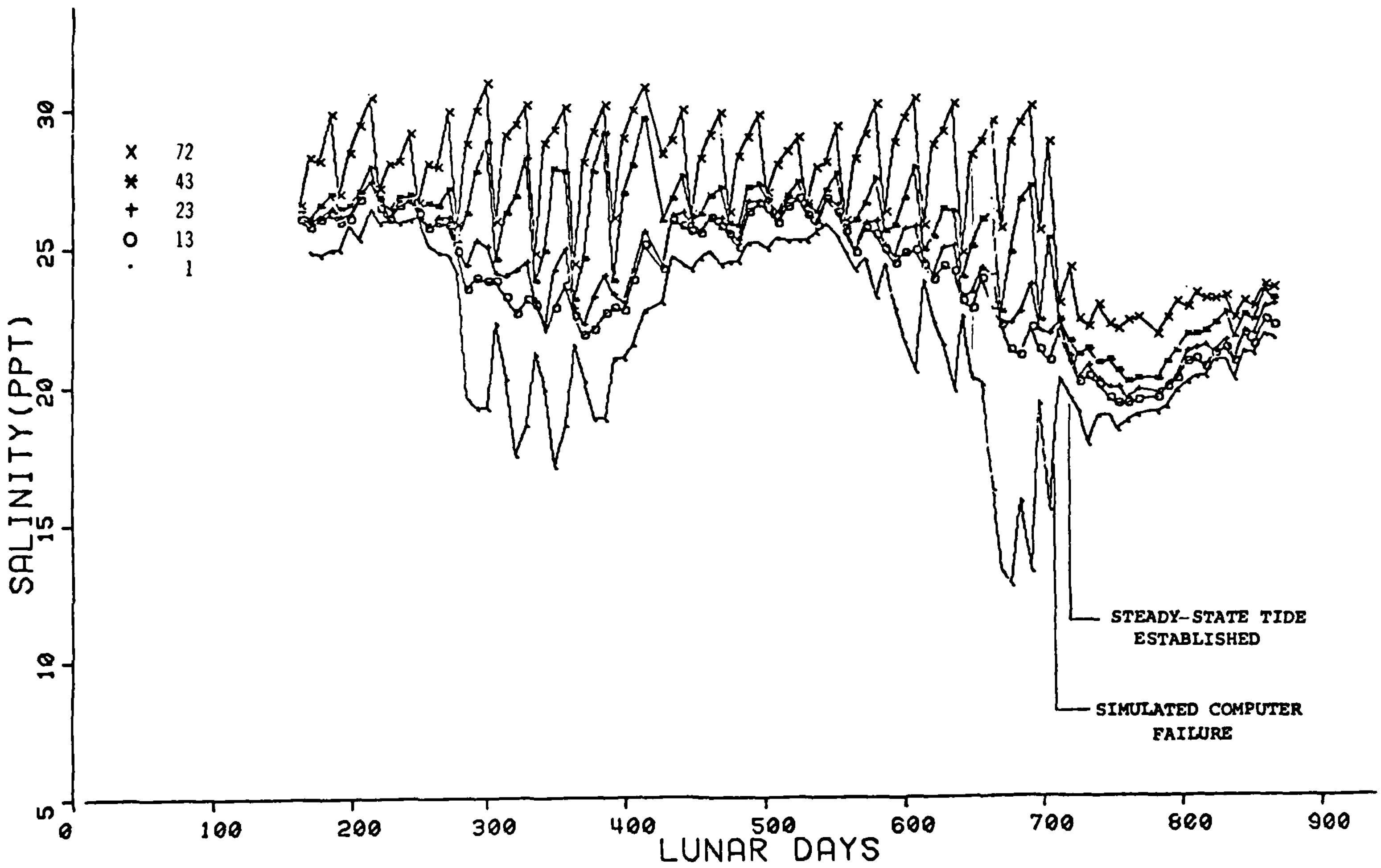


Figure 12. Station J-1-3 plan test salinity time-history (from Plate 47)

sta PO-1-1, PO-1-3, and PO-1-5, show smaller to no neap-spring salinity variability (Plates 48, 50, 51, 55, 56, 63, 64, and 65, respectively).

45. Salinity sensitivity to the lunar monthly tidal cycle tends to decrease with distance above the York Spit Channel, then it increases again in the upper bay above range CB-5. Sta CB-3-4 (Plate 60), located in the main channel below the Potomac River, is an exception showing a distinct surface response, possibly related to interaction with Potomac Estuary dynamics. Sta CB-3-6 and CB-3-8 (Plates 61 and 62), and stations along ranges CB-4 and CB-5 (Plates 66-72) generally show much reduced to little detectable salinity variation with respect to the neap-spring cycle. Stations in Craighill Channel, CC-1, CC-2, and CC-3 (Plates 75, 76, and 77, respectively), above range CB-5 and the Chesapeake Bay Bridge at Annapolis, reveal a slightly increased middepth salinity response to the monthly tidal cycle compared with ranges CB-4 and CB-5. The upper eastern shore station sampled in the Chester River (sta CH-1-1, Plate 73) also illustrates some neap-spring salinity variability. Stations within the Patapsco River (Plates 78-90), and the Magothy River station (MA-1-1, Plate 74), immediately below the Patapsco River, generally illustrate little to no distinct neap-spring sensitivity. Stations at upper bay ranges CB-6 and CB-7 (Plates 91-100) again illustrate distinct salinity response to the monthly cycle, although salinity variations are not as great as those of the lower bay stations. Figure 13 (from Plate 94) illustrates the plan test time-history salinity plot for sta CB-6-3 with the appropriate tide labeled on middepth observations.

46. Interaction with changing discharge and missing sampling values complicate interpretation of salinity responses to the monthly tidal cycle. As indicated in the time-history salinity plots, variations in response characteristics exist within stations and from station to station throughout the model. Some stations appear unaffected by the variable tides, some stations appear better mixed during each spring tide and more stratified during each neap tide (Figure 13), other stations appear better mixed only during the larger spring tide (S_1, Figure 11), and many stations show various combinations of the above cases. At most

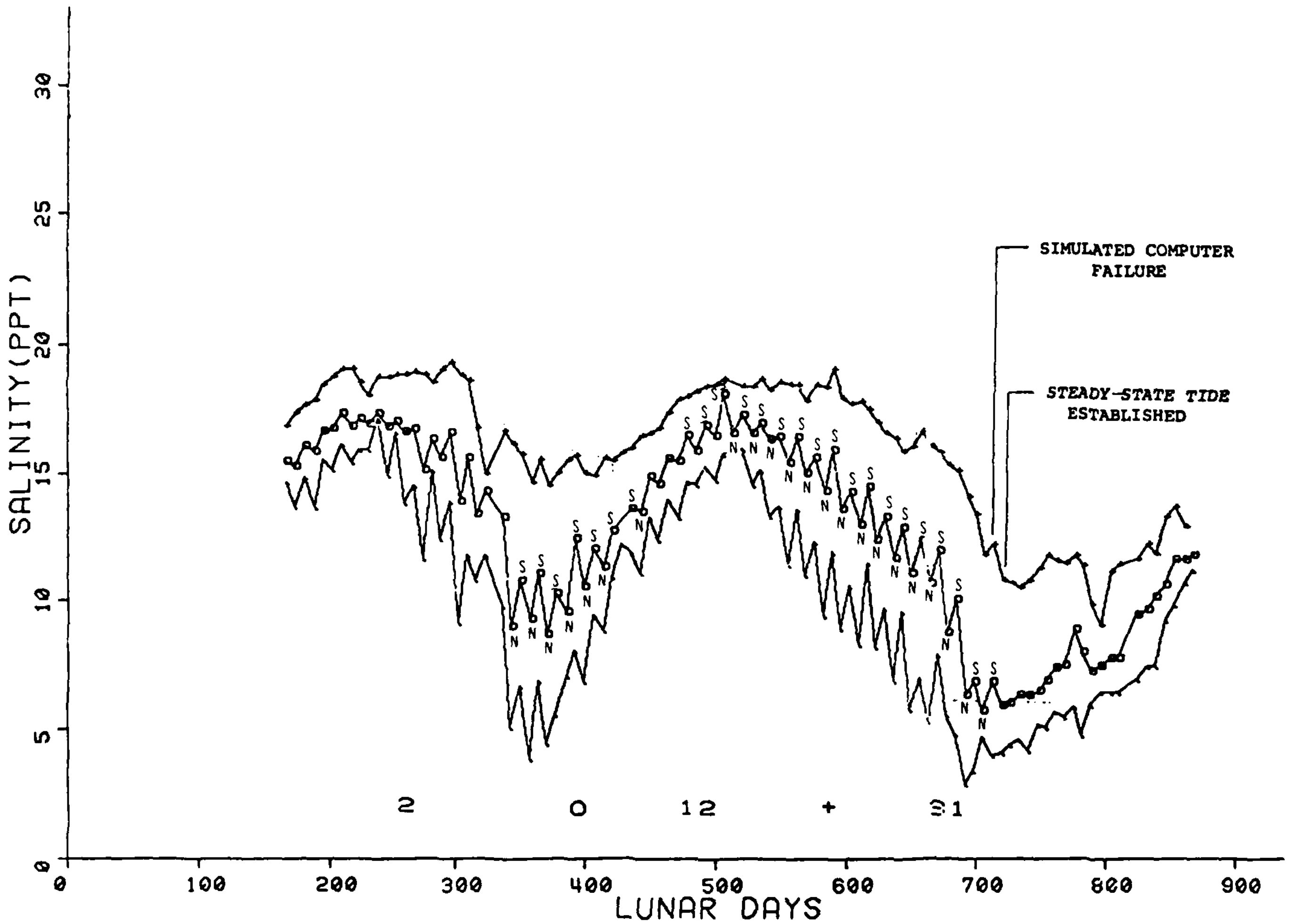


Figure 13. Station CB-6-3 plan test salinity time-history (from Plate 94)

stations, salinity structure and distribution are noticeably different during the last 150 lunar days of testing under repetitive cosine tide generation than during variable tide generation. Figure 12, James River sta J-1-3, provides an excellent example.

47. The dynamics of salinity response to variable tides may have a major influence on salinity intrusion and distribution within the estuary. Summarization of salinity conditions by averaging over monthly sampling time periods may oversimplify and eliminate these important variations. Little is presently known about the processes and responses of this complex tidal neap-spring salinity interaction, and it is beyond the intent and scope of this study to elaborate on this phenomenon. Additional research is necessary to fully understand the mechanics and associated implications of neap-spring tidal response characteristics.

48. The third and final consideration given to base and plan time-history salinity values are isolated perturbations from the generally consistent response trends to freshwater discharge and neap-spring tidal cycle variability. These perturbations are less numerous, and salinity variations over time are more gradual during the plan test. It is often difficult to distinguish small response differences associated with channel deepening from anomalous values associated with possible sampling, analysis, and/or boundary control problems. As an example, one of the most obvious base and plan response differences at most stations throughout the model occurs during the high discharge period of water year 1965 where base test salinities generally illustrate a more abrupt response to increased discharge than during the plan test. More precise boundary control during a plan test generally results through procedures and experience developed during preliminary base tests, for example, better anticipation of required sump adjustments for freshwater hydrograph conditions. Although the Baltimore Harbor base test was the first experience with this drought-type hydrograph, no major boundary control problems were identified; thus, boundary control differences between base and plan tests do not seem to account for this type of "random" salinity response difference.

Reliability of results

49. These three basic salinity response characteristics (variations to discharge, to tide, and isolated perturbations) are considered in defining a basis for discussing plan and base differences. The error band for individual plan-to-base salinity value comparisons (comparing two values each of which has a 0.5 to 1.0 ppt error band) in this study is considered to be between 1 and 2 ppt. Consistent trends during specific periods or conditions, illustrated on time-history difference plots, adds credibility to individual comparison values and increases their overall reliability (i.e. reduces error band toward the smaller value). Frequency-of-occurrence data (Table 18 and Figure 10) summarize plan-to-base salinity differences during the variable tide portion of the study and enable a quantitative classification approach. Stations demonstrating "appreciable" plan-to-base salinity variations are defined as those stations with 10 percent or more of their surface, middle, or bottom depth comparison values greater than ±2 ppt. Plates 33-100, Table 18, and Figure 10 should be referred to in the following discussions.

Lower bay

50. Surface salinity differences greater than ±2 ppt occur with substantial frequency at Chesapeake Bay entrance sta CB-0-1 and CB-0-2 (Plates 33 and 34). These differences are associated with random response and do not illustrate any distinct trends or patterns. No distinct trends in plan-to-base salinity differences are apparent at Cape Henry Channel sta CPH-1 and CPH-2 or adjacent entrance sta CB-0-3. Random responses do exist, for example, during the high discharge period of water year 1965, however, these variations do not occur with substantial frequency. The six stations located in the maintained York Spit Channel area (YSC-1, YSC-2, CB-1-5, YSC-3, YSC-4, and YSC-5, Plates 38-43) show a slight tendency toward increased salinity during the plan test. Only surface depths at sta YSC-1, YSC-2, and YSC-3 indicate appreciable salinity increases during the plan test compared with the base test. Although differences again appear to be associated with random responses, many of the individual increases are the result of more pronounced salinity peaks at the time of spring tides for the plan than for the base. Salinity

differences at sta CB-1-7 and CB-1-2 (Plates 44 and 45), respectively east and west of York Spit Channel, are generally within the ±2 ppt band.

51. The two James River stations (Plates 46 and 47) illustrate a trend of reduced salinity in the deep water during the plan test. The bottom depth, 43 ft, at sta J-1-2 shows a reduced salinity intrusion characteristic during the plan test, whereas the surface indicates increased salinity. At sta J-1-3 the three-quarter depth sample, also at 43 ft, reflects a similar reduced salinity intrusion (approximately 20 percent of the plan test observations at this depth are at least 2 ppt fresher than base test observations) while no appreciable plan-to-base salinity variations exist at the 72-ft bottom depth. York River sta Y-1-2 (Plate 49) also illustrates an appreciable bottom salinity intrusion decrease during the plan test. The well developed neap-spring salinity variability of the base test is noticeably missing during much of the plan test. No conclusive explanations can be provided for the apparent reduced bottom salinity intrusion for these lower tributary stations, although channel deepening and/or variations in neap-spring characteristics associated with channel deepening may be the cause. Salinity differences at the other York River sta Y-1-1, and Mobjack Bay sta MB-1-1 and MB-1-3 are generally within the ±2 ppt band.

52. The remaining lower bay stations sampled within Rappahannock Shoal Channel (sta RSC-1, RSC-2, and RSC-3) and along main bay ranges CB-2, CB-3, and CB-4 illustrate no appreciable plan-to-base salinity differences. The only distinct variations indicated, middepth at sta CB-2-5 (Plate 53), are the result of an inadvertently changed sampling depth from 12 ft during the base test to 22 ft during the plan test. Rappahannock River sta R-1-1 and R-1-2 (Plates 55 and 56) also indicate no appreciable or distinct salinity differences; random responses are evident during the high-flow period of water year 1965 where plan test surface values appear to have reacted to increased discharge sooner and more gradually than during the base test. Potomac River stations illustrate a similar but increased random response trend. Surface values are quite erratic in both base and plan tests. Appreciable salinity differences are indicated at sta PO-1-1 where plan test surface values are lower

during high-flow periods and higher during low-flow periods. A similar, but less pronounced, pattern was observed at sta PO-1-3. Plan test surface salinity values are also appreciably lower than base test values during high-flow periods at sta PO-1-5.

53. An overall view of lower main bay base and plan salinity differences indicates many more occurrences of positive values (increased salinity during plan test) than negative values on the plan minus base differences plots. This trend generally holds true at channel stations where the depth was increased and at bay or river stations where there was no depth change. Most of these differences, however, are within the ±2 ppt band.

Upper bay

54. Major plan-to-base salinity variations are found at upper bay stations above the constriction at range CB-4. Only Magothy River sta MA-1, and sta CB-7-1 have less than 10 percent of their comparison salinity values larger than ±2 ppt. The remaining 30 upper bay stations illustrate appreciable plan-to-base salinity differences.

55. Sta CB-5-2 and CB-5-6 (Plates 69 and 72), away from the naturally deep channel at this range, illustrate a slightly more stratified water column during the plan test with a fresher surface layer and saltier bottom layer compared with the base test. This trend becomes better developed with time into the modal year. With the exception of the surface layer, sta CB-5-4 (Plate 70) adjacent to the natural channel indicates a general trend of increasing salinity difference with time and increased depth; i.e., plan waters become saltier than base waters with time and bottom salinity differences (plan minus base) are greater than at any other depth. A similar trend of increasing salinity difference with time is indicated at sta CB-5-5 (Plate 71). The middepth values (48- and 57-ft depths) at this station illustrate the largest salinity differences. This is the first station with more than 25 percent of the difference values greater than 2 ppt. Over 40 percent of the middepth differences are greater than 2 ppt. Plan-to-base salinity differences are somewhat smaller (below appreciable occurrences) at the deepest depth sampled than at the middle depths.

56. Salinity differences are again found to increase with time at the eastern shore Chester River sta CH-1-1 (Plate 73). Bottom depth salinity difference values increase just enough during the latter parts of the plan test to classify this station as illustrating appreciable plan-to-base salinity differences. Across the bay at the western shore Magothy River sta MA-1-1 (Plate 74) no appreciable plan-to-base salinity differences are found, although during high-flow periods plan test salinities are somewhat lower than base test salinities.

57. Plan-to-base salinity differences are found to increase progressively up Craighill Channel, in the main bay, toward the entrance to Patapsco River. Middle and bottom depths at sta CC-1 (Plate 75) indicate substantially saltier water during the plan test. Over 23 percent of middepth and 28 percent of bottom depth plan test salinity values were greater than base test values by more than 2 ppt. Surface samples during the plan test high-flow periods are somewhat fresher than those of the base test. This trend increases at sta CC-2 and CC-3 (Plates 76 and 77) with plan test surface layers illustrating substantially fresher conditions for longer periods of time, 26 and 42 percent of the observations, respectively, and with middle and bottom depths illustrating additional increases in salinity during the plan test. Over 70 percent of the plan test bottom values were saltier than base test values by more than 2 ppt at sta CC-3. Positive bottom and middepth salinity differences (higher salinity druing plan test) at these three stations show a direct relationship with the hydrograph--as freshwater discharge increases or decreases so do salinity differences, and negative surface differences (i.e. increased freshness during plan test) exhibit an inverse relationship with discharge. Thus, plan test stratification (surface-to-bottom salinity variation) tends to increase during high-flow periods and tends to decrease during low-flow periods to a slightly higher stratification than the base test.

58. In general, a similar consistent response trend of increasing salinity difference progressing up the main Baltimore Harbor Channel in Patapsco River (sta PR-1-3, BC-3, BC-4, PR-2-2, PR-3-1/FM-1, FM-2, and FC-1, Plates 78-84 exists, with saltier middle and bottom depths during

the plan test. Bottom depths at these seven main channel stations illustrate the greatest salinity increases with more than 80 percent of the plan test values saltier than base test values by more than 2 ppt. In fact, over 55 percent of bottom depth plan test salinity values are more than 5 ppt saltier than base test values at sta PR-2-2, PR-3-1/FM-1, and EC-1 in upper Patapsco River. Surface differences have the tendency to decrease with distance up the river, although most stations indicate appreciably fresher water during the plan test compared with the base test. Surface and bottom depth salinity values at sta FM-2 are quite erratic during the plan test; however, appreciably saltier conditions are indicated throughout the water column during the plan test. Surface salinity values at sta EC-1, the uppermost main channel station sampled in Patapsco River, also indicate some erratic plan test fluctuations. Over 16 percent of the comparison observations indicate appreciably fresher plan test surface values compared with base test values while almost 24 percent of the observations indicate appreciably saltier plan test surface values.

59. Figure 14 (from Plates 78, 81, and 84) summarizes the general trend of increasing salinity differences with distance up the Patapsco River for selected main channel stations. The trend of increasing salinity difference with time is also indicated. Salinity differences at sta PR-2-2 provide an excellent example of the relationship between discharge and stratification, with fresher surface and saltier middle and bottom depths during high-flow periods of the plan test. Stratification during high-flow periods is drastically higher for the plan test than for the base test but only slightly higher during low-flow periods. Sta PR-2-2, PR-3-1/FM-1, and EC-1 in the upper Patapsco River illustrate the greatest salinity differences associated with channel deepening. Between lunar days 249 to 709, periods 2 through 6, bottom plan test salinity values at these stations are on the average 6 to 7 ppt saltier than base test values. Salinity differences are greatest during high flow periods, with bottom plan test values over 10 ppt greater than base test values during the modal year just prior to loss of tide control. This characteristic of increasing salinity difference during

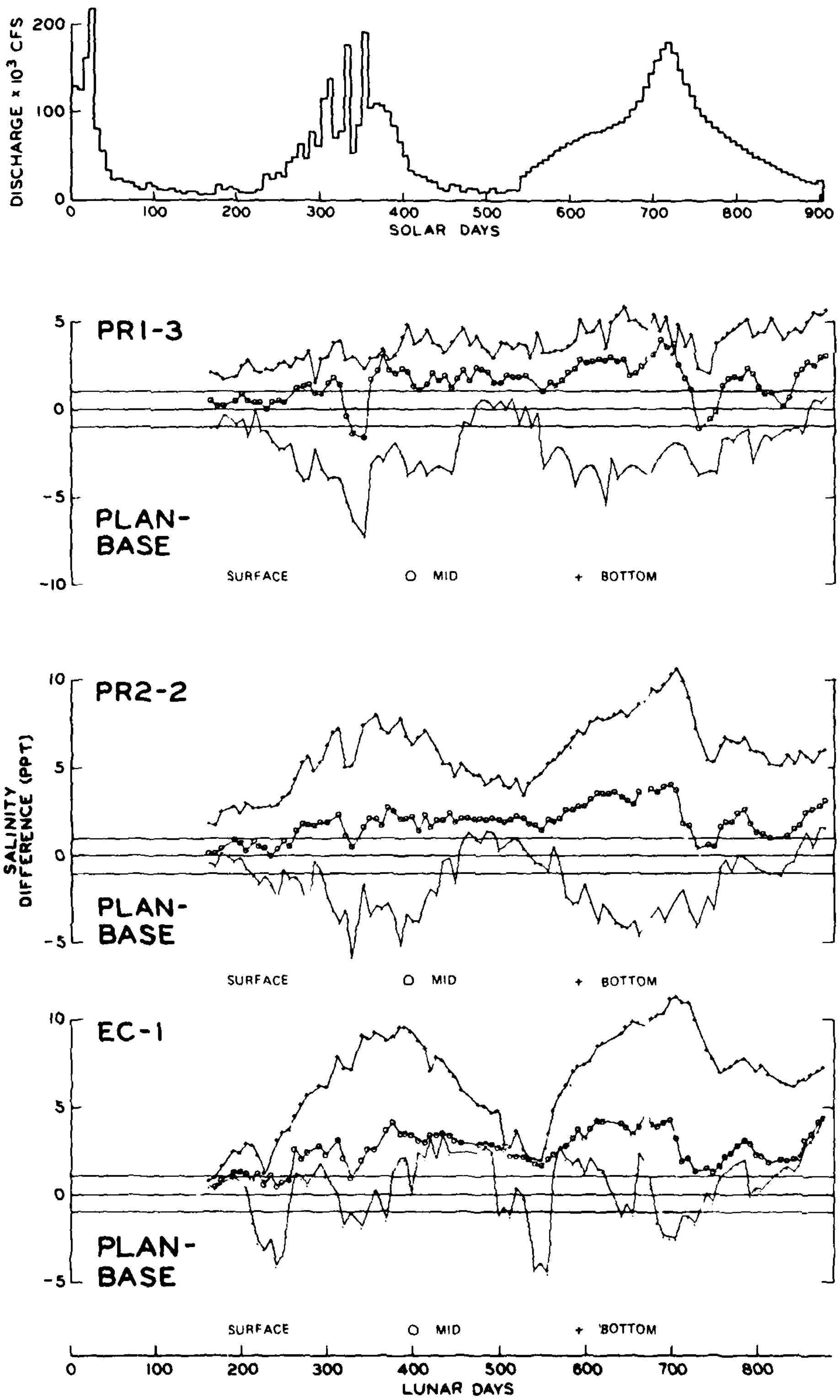


Figure 14. Patapsco River main channel plan minus base salinity difference summary (from Plates 78, 81, and 84)

high-flow periods is an example where averaging over specific predetermined time periods without full consideration of the freshwater inflow may result in anomalous values, reduced salinity variability, and improper interpretations.

60. Sta FB-1 in Ferry Bar Channel and sta-CBC-1 (Plates 85 and 86) in Curtis Bay Channel, both in side channels of the upper Patapsco River, indicate appreciably increased salinity throughout the water column during the plan test. Bottom depths show the greatest salinity increases. At the other side channel sta SP-1 (Plate 88), located adjacent to Sparrows Point, plan test surface values are appreciably fresher while middle and bottom depths are appreciably saltier than base test values. More than 70 percent of plan test bottom values at these side channel stations are greater than 2 ppt saltier than base test values and more than 15 percent of these values are greater than 5 ppt saltier. As at other stations in this area, the degree of stratification at these stations is much greater during the plan test high-flow periods than for the base test and slightly greater during low-flow periods. A general trend of increasing plan test salinity with time is indicated in salinity difference plots for this group of Patapsco River stations.

61. Salinity differences at sta PR-2-1 (Plate 87), in shallow water away from the main channel in mid-Patapsco River, are much reduced from those at sta PR-2-2 (Plate 81) in the main channel. The 14-ft-depth bottom sample at sta PR-2-1 indicates a general trend of increased salinity difference over time with plan test values becoming appreciably greater than base test values. Approximately 64 percent of plan test bottom values are between 2-5 ppt saltier than base test values. Over 14 percent of plan test surface values are appreciably fresher than base test values during high-flow periods and 13 percent of the plan test values are appreciably saltier than base test values during the low-flow period between water year 1965 and the modal year. Stratification is greater for the plan test than for the base test during high-flow periods, but essentially unchanged during low-flow periods.

62. Salinity differences at sta PR-1-2 and PR-1-1 (Plates 89 and 90) in shallow water at the entrance to Patapsco River also indicate a

decreased response with channel deepening compared with main channel sta PR-1-3 (Plate 78). Reduced but appreciable plan-to-base differences are found at bottom depths for the shallow-water stations with less than 30 percent of plan test values appreciably saltier than base test values. Appreciable surface differences are found only at sta PR-1-2 with 23 percent of plan test values fresher than base test values by more than 2 ppt. Stratification changes are similar to those for sta PR-1-3.

63. Sta BC-2 and BC-1, east of Patapsco River in the maintained main bay connecting channel leading from Patapsco River to the C&D Canal, illustrate a greater frequency of appreciable plan-to-base salinity differences compared with sta PR 1-2 and PR 1-1. Middepth comparisons illustrate the greatest differences with over 30 percent of plan test values saltier than base test values by more than 2 ppt. Sta BC-2, closer to Patapsco River, illustrates greater differences than sta BC-1. These two stations are the most upstream to illustrate distinct plan-to-base differences with respect to stratification responses.

64. With the exception of the surface at sta CB-6-1 and the bottom at sta CB-7-3, distinct salinity differences are not obvious in base and plan time-history plots for the remaining main bay stations along ranges CB-6 and CB-7 (Plates 93-100). Much reduced but still appreciable plan-to-base salinity differences are indicated for bottom depths at most of these stations. Plan test salinity differences are again found to increase with time. Sta CB-6-1, in shallow water adjacent to Craighill Channel, illustrates about a 5-ppt surface salinity decrease during the plan test modal year compared with the base test; over 30 percent of plan test surface salinities are fresher than base test values by more than 2 ppt, over 15 percent of these values are greater than 5 ppt fresher. The bottom depth at this station does not illustrate appreciable plan-to-base salinity differences. The largest bottom salinity differences at sta CB-7-3 also occur during the modal year. About 25 percent of the plan test bottom values are saltier then base test values by more than 2 ppt.

65. To summarize, 30 of the 32 upper bay stations (above the constriction at range CB-04) illustrate appreciable plan-to-base salinity

differences. Fresher surface layers and saltier middle and bottom layers are indicated following channel deepening. Plan test stratification increases substantially during high-flow periods and tends to decrease during low-flow periods generally to slightly higher stratification than the base test. A general trend of increasing salinity with time, comparing plan-to-base tests, is illustrated at most upper bay stations. Salinity differences increase progressively up the main bay channel and into the Patapsco River. The seven deepened main channel stations in the Patapsco River illustrate the greatest salinity differences with over 50 percent of the plan test bottom values saltier than base test values by more than 5 ppt. Largest increases, over 10 ppt, are found at bottom depths during the high-flow period of the modal year at the three upper channel stations. Salinity differences decrease with distance from deepened channels toward shallow-water stations. Plan-to-base salinity and vertical distribution differences during dynamic conditions indicate possible changes to upper bay and especially the Patapsco River circulation as a result of proposed channel deepening.

PART IV: SUMMARY AND CONCLUSIONS

66. No major plan-to-base velocity variations are indicated at any of the sampled stations. Slight trends in velocity differences associated with channel deepening indicate subtle variations in the hydrodynamic characteristics during the steady-state tests. The general tendency toward reduced velocity (amplitudes) during plan tests meets expectations of increased cross-sectional area associated with channel deepening. A general trend of slightly increased flood dominance (between 0.10 and 0.25 fps) is indicated at lower bay stations (stations below the constriction at range CB-04, adjacent to Patuxent River) during plan tests compared with base tests. This changed flow distribution is associated with an increased flood velocity and a decreased ebb velocity. The deepened channels leading to Baltimore Harbor can enhance salinity intrusion into the main estuary. A return flow of estuarine water may exist in the shallower nonsampled areas.

67. The few upper bay stations sampled for velocity generally show little dominance variations (±0.10 fps) with both flood and ebb velocities somewhat reduced during the plan test. Velocities in the Patapsco River are quite low during both base and plan tests requiring special drogue velocity measurements. No shift in flow dominance is identified that can be used to substantiate or refute changes to, or the presence of, a three-layer flow circulation pattern within the Patapsco River. Hydrodynamic testing during dynamic conditions associated with variable freshwater discharges and variable tides is required for detailed analysis of this circulation phenomenon.

68. Three basic trends in salinity time-histories exist during dynamic salinity testing that can be effected by channel deepening. The predominant underlying trend at most stations is an inverse relationship between freshwater discharge and salinity concentration--as discharge increases salinity decreases. This sensitivity to discharge generally decreases down the bay toward the ocean entrance and with increasing water depth. Superimposed on this discharge response is a shorter frequency response associated with neap-spring tidal variability producing

a sawtooth pattern in time-history salinity plots. Sensitivity to this tidal response generally increases with approach to the ocean entrance and with increasing depth below the surface. Little is presently known about the processes and responses of this complex tidal neap-spring interaction although it is shown to have significant influence on salinity intrusion and distribution within the estuary. The third trend is a random response or noise in the data, the cause of which is not identified.

69. This study indicates some major and some minor plan-to-base salinity differences associated with channnel deepening. For the purposes of this study, stations demonstrating appreciable plan-to-base variations are defined as those stations with 10 percent or more of their surface, middle, or bottom depth comparison values greater than ±2 ppt. Lower main bay stations, from the constriction at range CB-04 and below, illustrate a slight trend of saltier deeper water during the plan test although plan minus base differences are not generally greater than the defined appreciable level. Stations in the bay entrance and York Spit Channel area indicate appreciable plan-to-base salinity differences. These differences, at surface depths, are associated with random and abrupt responses generally occurring during the base test and not during the plan test.

70. The other lower bay stations indicating appreciable plan-to-base salinity differences are located at the entrance to the James, York, and Potomac Rivers. The two James River stations indicate a reduced salinity intrusion with fresher deep water during the plan test. The deeper York River station also indicates an appreciable bottom salinity intrusion decrease during the plan test and the well-developed neap-spring salinity variability of the base test is noticeably missing during much of the plan test. The reduced salinity intrusion in these lower bay tributaries may be associated with channel deepening in the main bay and the Patapsco River. Salinity differences at the other York River station, Mobjack Bay stations, and Rappahannock River stations indicate some random responses with plan test salinities of a more gradual nature compared with base test salinities; however, these variations are not at appreciable levels. Random responses are again at appreciable

levels at two of the three Potomac River stations.

71. Major salinity differences associated with channel deepening are found at the upper bay stations from Kent Island and above. The water column at most upper bay stations generally appears more stratified during the plan test compared with the base test. Plan minus base salinity differences show a direct relationship with the freshwater hydrograph--as freshwater discharge increases so do salinity differences, illustrating both stratification and salinity difference increases during high-flow periods. Plan test surface values are generally fresher than base test values while middle and bottom depth values are saltier during the plan test. With increasing time a general trend of increasing plan test salinity compared with base test salinity is also indicated in most salinity difference plots.

72. Plan minus base salinity differences increase progressively up the deepened channel in the main upper bay and the Patapsco River. Bottom depths at the seven main channel stations in the Patapsco River illustrate the greatest salinity increases with more than 80 percent of plan test values saltier than base test values by more than 2 ppt and over 55 percent of the values saltier by more than 5 ppt. The largest differences, with bottom plan test values more than 10 ppt saltier than base test values, occur at the three uppermost deepened channel stations in the Patapsco River during the modal year high-flow period just prior to loss of tide control.

73. Salinity differences attenuate with distance from the deepened channel toward shallow-water stations. Stations in nondeepened side channels within the Patapsco River and the main bay connecting channel leading to the C&D Canal indicate a somewhat reduced salinity response compared with adjacent main channel stations. Plan-to-base differences at shallow-water stations within the Patapsco River and along ranges CB-5, CB-6, and CB-7 indicate a much reduced salinity sensitivity to channel deepening, although with increasing time the frequency of salinity differences greater than 2 ppt increases above the defined 10 percent appreciable level.

74. In conclusion, the Baltimore Harbor and Channels Deepening

Study investigated parameters that indicate hydrodynamic change associated with channel improvements. Steady-state (constant freshwater discharge and repeated cosine tide) velocity tests indicate that the deepened channels resulted in little change to velocity. Subtle variations in flow distribution at lower bay stations below the Patuxent River indicate additional intrusion into the main estuary. No shift in flow distribution can be detected at upper bay or Patapsco River stations during the steady-state velocity tests.

75. Dynamic (time varying freshwater discharge and repeated 28-lunar-day variable tides) salinity tests indicate major salinity differences associated with channel deepening. Most lower bay stations illustrate a trend of increased salinity after deepening. Plan minus base salinity differences increase progressively up the deepened channel in the main bay above Kent Island and into the Patapsco River. High-flow periods illustrate largest differences with fresher surface and saltier middle and bottom depths showing increased stratification and increased total salt as a result of channel deepening. Greatest salinity differences, with plan test values up to 10 ppt saltier than base test values, occur at bottom depths in the deepened upper Baltimore Harbor Channel in the Patapsco River. Salinity differences decrease with distance from the deepened channel. However, a general trend of increasing salinity with time, comparing plan and base tests, is illustrated at most upper bay stations.

76. Indicated differences in salinity, intrusion, and vertical distribution during the model study demonstrates the need for careful consideration to possible changes in estuarine dynamics and in sediment, nutrient, and pollutant transport as a result of proposed channel improvements.

Table 1

Freshwater Discharge

Inflow Number	Long-Term Average Flow Distribution Percent	Long-Term Average Flow cfs	High-Flow Period cfs	Low-Flow Period cfs
1	1.0	700	1,160	290
2	0.4	300	497	124
3	1.4	1,000	1,657	414
4	10.3	7,500	12,429	3,107
5	3.8	2,750	4,557	1,139
6	4.1	2,940	4,872	1,218
7	0.6	426	706	177
8	3.4	2,452	4,063	1,016
9	0.8	602	997	250
10	11.0	7,964	13,197	3,299
11	1.3	911	1,510	377
12	0.3	239	396	99
13	0.9	634	1,051	263
14	1.1	830	1,375	344
15	53.2	38,500	63,800	15,950
16	0.5	400	663	166
17	0.7	519	860	215
18	0.3	196	325	81
19	1.2	845	1,400	350
20	2.3	1,675	2,776	694
21	1.4	1,031	1,709	427
	Total Discharge	72,414	120,000	30,000

Table 2

Velocity Sampling Depths

Station	Depth, ft Base	Depth, ft Plan	Station	Depth, ft Base	Depth, ft Plan
CPH-1	4	4	RSC-2	4	4
	23	27		24	26
	42	50		44	49
YSC-1	4	4	OD-4	4	4
	24	24		42	42
	45	45		80	80
CB-1-5	4	4	CC-2	4	4
	22	26		22	22
	35	48		41	50
YSC-4	4	4	BC-2	4	4
	22	26		23	23
	40	48		42	42
OD-1	4	4	BC-4	4	4
	42	42		21	27
	81	81		37	50
OD-2	4	4	FM-1	4	4
	31	31		22	26
	58	58		40	48
OD-3	4	4			
	20	20			
	37	37			

Table 3

Velocity Characteristics During Spring Tide, 120,000-cfs Inflow Test

		Base Test						Plan Test					
						Maximum Velocity, fps*						Maximum Velocity, fps*	
Range	Station	Depth ft	Phase deg	Amplitude fps	Offset fps	Flood	Ebb	Depth ft	Phase deg	Amplitude fps	Offset fps	Flood	Ebb
CPH	1	4	200	2.23	-0.71	1.51	2.94	4	229	2.05	-0.85	1.19	2.90
CPH	1	23	219	1.93	-0.19	1.73	2.12	27	217	1.78	-0.04	1.74	1.83
CPH	1	42	206	1.35	0.27	1.62	1.07	50	209	1.51	0.28	1.79	1.23
YSC	1	4	231	3.29	-0.38	2.91	3.67	4	232	2.67	-0.17	2.50	2.84
YSC	1	24	224	2.75	0.46	3.21	2.29	24	228	2.84	0.54	3.39	2.30
YSC	1	45	221	1.94	0.57	2.52	1.36	45	226	2.41	1.04	3.45	1.36
CB-1	5	4	257	2.01	-0.15	1.85	2.16	4	256	1.75	-0.26	1.49	2.01
CB-1	5	22	250	1.82	0.32	2.14	1.50	26	238	1.85	0.48	2.34	1.36
CB-1	5	35	224	1.45	0.17	1.62	1.28	48	219	1.32	0.33	1.65	0.99
YSC	4	4	269	1.60	-0.36	1.24	1.96	4	271	1.56	-0.39	1.16	1.95
YSC	4	22	259	1.60	0.09	1.70	1.51	26	260	1.49	0.20	1.69	1.28
YSC	4	40	235	1.01	0.20	1.21	0.81	48	235	1.01	0.53	1.54	0.48
OD	1	4	266	1.80	-0.55	1.25	2.35	4	270	1.83	-0.42	1.40	2.26
OD	1	42	240	1.98	0.30	2.29	1.68	42	239	2.04	0.24	2.29	1.79
OD	1	81	225	1.38	0.18	1.57	1.19	81	229	1.58	0.01	1.59	1.57
OD	2	4	269	1.84	-0.53	1.30	2.38	4	268	1.72	-0.49	1.22	2.22
OD	2	31	276	1.90	0.37	2.27	1.52	31	271	1.82	0.38	2.20	1.43
OD	2	58	258	1.31	0.21	1.53	1.10	58	257	1.45	0.25	1.70	1.20
OD	3	4	274	1.99	-0.70	1.28	2.70	4	273	1.89	-0.63	1.25	2.52
OD	3	20	280	2.15	0.04	2.19	2.10	20	279	2.09	0.00	2.09	2.09
OD	3	37	258	1.73	0.19	1.92	1.53	37	260	1.60	0.22	1.83	1.37
RSC	2	4	242	1.16	-0.23	0.93	1.39	4	292	0.92	-0.11	0.80	1.04
RSC	2	24	233	1.24	0.13	1.37	1.10	26	279	0.86	0.16	1.02	0.70
RSC	2	44	198	0.81	0.20	1.01	0.61	49	252	0.46	0.15	0.62	0.31
OD	4	4	259	1.18	-0.47	0.70	1.65	4	312	0.98	-0.38	0.59	1.37
OD	4	42	246	0.87	0.36	1.24	0.50	42	313	0.89	0.27	1.16	0.62
OD	4	80	261	0.48	-0.00	0.48	0.48	80	271	0.39	0.04	0.43	0.34
CC	2	4	128	1.17	-0.35	0.82	1.53	4	120	0.89	-0.22	0.66	1.11
CC	2	22	119	0.88	0.11	1.00	0.77	27	124	0.73	0.18	0.92	0.54
CC	2	41	112	0.56	0.19	0.76	0.36	50	129	0.42	0.21	0.63	0.21
BC	2	4	138	0.56	-0.10	0.45	0.67	4	135	0.42	-0.06	0.35	0.48
BC	2	23	87	0.19	0.06	0.25	0.12	23	101	0.14	0.03	0.18	0.11
BC	2	42	54	0.23	0.06	0.29	0.17	42	120	0.07	-0.00	0.06	0.07
BC	4	4	69	0.41	0.14	0.55	0.27	4	104	0.41	0.02	0.43	0.38
BC	4	21	59	0.37	0.04	0.41	0.33	27	126	0.31	0.07	0.38	0.23
BC	4	37	82	0.26	0.19	0.46	0.06	50	92	0.30	0.05	0.35	0.24
FM	1	4	78	0.08	0.03	0.11	0.04	4	62	0.12	-0.02	0.10	0.15
FM	1	22	83	0.16	0.00	0.16	0.15	26	64	0.14	0.00	0.14	0.14
FM	1	40	53	0.18	0.03	0.21	0.15	48	98	0.08	0.03	0.12	0.05

* Maximum flood and ebb velocities are the peak values of the cosine curve fit of the data rather than the peak observed values.

Table 4

Velocity Characteristics During Neap Tide, 120,000-cfs Inflow Test

			Base Test					Plan Test				
						Maximum Velocity, fps*						Maximum Velocity, fps*	
Range	Station	Depth ft	Phase deg	Amplitude fps	Offset fps	Flood	Ebb	Depth ft	Phase deg	Amplitude fps	Offset fps	Flood	Ebb
CPH	1	4	230	1.14	-0.66	0.48	1.80	4	230	1.17	-0.46	0.71	1.64
CPH	1	23	252	1.18	-0.02	1.16	1.20	27	222	1.37	0.21	1.58	1.10
CPH	1	42	207	0.79	0.28	1.07	0.51	50	216	1.00	0.20	1.21	[illegible]
YSC	1	4	227	1.93	-0.36	1.56	2.29	4	242	1.78	-0.11	1.67	1.89
YSC	1	24	226	2.07	0.49	2.57	1.58	24	245	1.89	0.76	2.66	1.12
YSC	1	45	221	1.65	0.51	2.17	1.13	45	245	1.84	1.01	2.85	0.82
CB-1	5	4	261	1.17	-0.32	0.84	1.49	4	267	1.21	-0.26	0.95	1.47
CB-1	5	22	250	1.19	0.33	1.53	0.85	26	240	1.31	0.47	1.78	0.83
CB-1	5	35	228	1.00	0.14	1.14	0.86	48	226	1.20	0.35	1.56	0.84
YSC	4	4	275	1.14	-0.40	0.74	1.54	4	285	0.94	-0.32	0.62	1.26
YSC	4	22	264	1.06	0.05	1.11	1.01	26	274	0.84	0.22	1.06	0.61
YSC	4	40	275	0.58	0.16	0.74	0.42	48	260	0.82	0.59	1.41	0.23
OD	1	4	272	1.17	-0.44	0.73	1.61	4	273	1.24	-0.54	0.70	1.79
OD	1	42	249	1.59	0.11	1.70	1.48	42	246	1.48	0.14	1.63	1.33
OD	1	81	227	1.21	-0.02	1.19	1.24	81	226	1.32	-0.01	1.30	1.34
OD	2	4	272	1.15	-0.37	0.77	1.52	4	266	1.10	-0.38	0.71	1.48
OD	2	31	279	1.15	0.29	1.45	0.85	31	273	1.14	0.32	1.47	0.81
OD	2	58	264	1.00	0.16	1.16	0.83	58	258	1.05	0.18	1.23	0.87
OD	3	4	276	1.36	-0.59	0.77	1.95	4	271	1.43	-0.50	0.93	1.94
OD	3	20	280	1.34	0.02	1.36	1.31	20	273	1.43	0.06	1.49	1.36
OD	3	37	267	1.16	0.15	1.32	1.00	37	262	1.00	0.20	1.21	0.79
RSC	2	4	303	0.70	-0.29	0.41	1.00	4	307	0.56	-0.28	0.27	0.84
RSC	2	24	304	0.83	0.01	0.84	0.82	26	301	0.63	0.13	0.76	0.50
RSC	2	44	250	0.45	0.21	0.67	0.24	49	277	0.38	0.17	0.55	0.21
OD	4	4	314	0.60	-0.07	0.53	0.68	4	314	0.76	-0.36	0.40	1.12
OD	4	42	324	0.58	0.33	0.92	0.24	42	310	0.67	0.30	0.97	0.36
OD	4	80	257	0.18	0.01	0.20	0.16	80	285	0.22	-0.03	0.18	0.25
CC	2	4	160	0.85	-0.19	0.65	1.04	4	129	0.42	-0.12	0.30	0.54
CC	2	22	168	0.54	0.10	0.65	0.43	27	157	0.52	0.24	0.77	0.27
CC	2	41	171	0.62	0.18	0.80	0.44	50	141	0.27	0.09	0.36	0.18
BC	2	4	135	0.31	-0.06	0.24	0.37	4	139	0.40	-0.09	0.31	0.50
BC	2	23	125	0.06	-0.00	0.06	0.07	23	128	0.07	0.00	0.08	0.07
BC	2	42	142	0.06	0.00	0.06	0.06	42	134	0.07	-0.00	0.06	0.08
BC	4	4	106	0.32	0.00	0.32	0.32	4	66	0.34	0.00	0.35	0.33
BC	4	21	102	0.22	-0.01	0.21	0.23	27	85	0.26	0.05	0.32	0.21
BC	4	37	105	0.26	0.04	0.30	0.21	50	77	0.22	0.05	0.27	0.16
FM	1	4	104	0.05	-0.01	0.04	0.06	4	50	0.06	-0.01	0.05	0.08
FM	1	22	64	0.16	-0.01	0.15	0.17	26	69	0.07	0.02	0.09	0.04
FM	1	40	20	0.07	-0.01	0.06	0.09	48	52	0.07	0.00	0.07	0.07

* Maximum flood and ebb velocities are the peak values of the cosine curve fit of the data rather than the peak observed values.

Table 5

Velocity Characteristics During Spring Tide, 30,000-cfs Inflow Test

		Base Test						Plan Test					
						Maximum Velocity, fps*						Maximum Velocity, fps*	
Range	Station	Depth ft	Phase deg	Amplitude fps	Offset fps	Flood	Ebb	Depth ft	Phase deg	Amplitude fps	Offset fps	Flood	Ebb
CPH	1	4	226	1.89	-0.60	1.28	2.50	4	224	1.86	-0.54	1.31	2.41
CPH	1	23	221	1.81	-0.39	1.42	2.21	27	219	1.73	-0.36	1.36	2.10
CPH	1	42	200	1.05	0.05	1.10	1.00	50	207	1.24	0.03	1.28	1.21
YSC	1	4	229	3.30	0.17	3.47	3.13	4	233	2.95	0.50	3.46	2.44
YSC	1	24	226	2.86	0.27	3.13	2.59	24	228	2.95	0.45	3.40	2.50
YSC	1	45	221	1.77	0.10	1.88	1.66	45	229	2.27	0.40	2.68	1.87
CB-1	5	4	252	1.88	-0.10	1.78	1.99	4	254	2.06	-0.01	2.04	2.07
CB-1	5	22	242	1.54	0.07	1.62	1.46	26	244	2.00	0.27	2.27	1.73
CB-1	5	35	233	1.13	0.05	1.19	1.08	48	229	1.34	0.26	1.60	1.08
YSC	4	4	266	1.69	-0.18	1.51	1.88	4	266	1.37	0.00	1.37	1.37
YSC	4	22	259	1.43	-0.05	1.37	1.48	26	255	1.37	0.01	1.38	1.36
YSC	4	40	249	1.00	-0.02	0.98	1.03	48	252	0.85	-0.11	0.73	0.96
OD	1	4	268	1.83	-0.21	1.62	2.04	4	269	1.78	-0.10	1.68	1.88
OD	1	42	246	2.05	0.25	2.31	1.79	42	247	1.77	0.17	1.95	1.60
OD	1	81	229	1.12	0.42	1.54	0.69	81	230	1.26	0.30	1.57	0.95
OD	2	4	276	1.88	-0.26	1.62	2.14	4	273	1.72	-0.20	1.52	1.92
OD	2	31	277	1.93	0.23	2.16	1.69	31	275	1.69	0.15	1.84	1.54
OD	2	58	256	1.44	0.15	1.60	1.29	58	260	1.18	0.12	1.31	1.06
OD	3	4	283	1.87	-0.26	1.61	2.13	4	281	2.09	-0.39	1.69	2.49
OD	3	20	275	1.90	-0.12	1.78	2.03	20	276	2.26	0.01	2.28	2.24
OD	3	37	255	1.40	0.10	1.50	1.30	37	254	1.51	0.09	1.61	1.41
RSC	2	4	279	0.89	-0.17	0.72	1.06	4	288	0.79	-0.03	0.76	0.83
RSC	2	24	274	0.95	-0.05	0.89	1.00	26	283	0.68	-0.09	0.58	0.77
RSC	2	44	276	0.74	0.02	0.76	0.72	49	274	0.48	0.08	0.56	0.40
OD	4	4	305	0.71	-0.20	0.51	0.92	4	311	1.00	-0.22	0.77	1.22
OD	4	42	312	0.79	0.26	1.05	0.53	42	307	1.01	0.30	1.32	0.71
OD	4	80	272	0.57	0.19	0.76	0.38	80	256	0.53	0.15	0.69	0.38
CC	2	4	118	0.90	-0.05	0.85	0.95	4	125	0.72	-0.13	0.59	0.86
CC	2	22	118	0.96	0.06	1.02	0.90	27	116	0.84	0.24	1.08	0.59
CC	2	41	91	0.72	0.16	0.88	0.55	50	100	0.48	0.06	0.55	0.41
BC	2	4	144	0.55	-0.04	0.50	0.60	4	134	0.33	-0.04	0.28	0.37
BC	2	23	115	0.22	0.05	0.27	0.17	23	114	0.20	0.06	0.27	0.14
BC	2	42	132	0.09	0.02	0.11	0.06	42	93	0.11	0.00	0.11	0.11
BC	4	4	80	0.36	-0.01	0.34	0.37	4	54	0.29	0.07	0.36	0.22
BC	4	21	100	0.34	0.04	0.39	0.30	27	59	0.34	0.07	0.41	0.27
BC	4	37	66	0.39	0.19	0.58	0.20	50	78	0.48	0.01	0.49	0.46
FM	1	4	45	0.14	-0.01	0.13	0.15	4	48	0.07	0.00	0.07	0.07
FM	1	22	66	0.13	-0.00	0.13	0.13	26	64	0.08	0.04	0.13	0.04
FM	1	40	67	0.12	-0.00	0.12	0.12	48	77	0.14	0.00	0.14	0.13

* Maximum flood and ebb velocities are the peak values of the cosine curve fit of the data rather than the peak observed values.

Table 6

Velocity Characteristics During Neap Tide, 30,000-cfs Inflow Test

		Base Test						Plan Test					
						Maximum Velocity, fps*						Maximum Velocity, fps*	
Range	Station	Depth ft	Phase deg	Amplitude fps	Offset fps	Flood	Ebb	Depth ft	Phase deg	Amplitude fps	Offset fps	Flood	Ebb
CPH	1	4	243	1.42	-0.60	0.82	2.02	4	224	0.98	-0.21	0.77	1.19
CPH	1	23	224	1.05	-0.21	0.84	1.27	27	216	0.96	-0.07	0.89	1.04
CPH	1	42	211	0.81	0.03	0.84	0.77	50	219	0.74	0.05	0.80	0.69
YSC	1	4	230	2.19	-0.12	2.07	2.32	4	235	1.98	0.29	2.28	1.69
YSC	1	24	225	1.91	0.44	2.36	1.46	24	231	1.94	0.49	2.44	1.44
YSC	1	45	224	1.39	0.27	1.66	1.11	45	234	1.54	0.59	2.14	0.94
CB-1	5	4	259	1.36	-0.22	1.13	1.58	4	256	1.12	-0.01	1.10	1.14
CB-1	5	22	246	1.13	0.24	1.62	1.14	26	244	1.15	0.25	1.41	0.89
CB-1	5	35	239	1.17	0.11	1.29	1.05	48	234	0.81	0.26	1.08	0.54
YSC	4	4	266	1.03	-0.32	0.75	1.40	4	269	1.06	-0.13	0.92	1.19
YSC	4	22	271	1.17	0.07	1.25	1.09	26	260	1.12	0.21	1.34	0.91
YSC	4	40	244	0.67	0.18	0.86	0.49	48	253	0.76	0.23	0.99	0.52
OD	1	4	277	1.18	-0.38	0.80	1.56	4	270	1.29	-0.16	1.13	1.46
OD	1	42	252	1.33	0.28	1.61	1.05	42	252	1.46	0.26	1.73	1.20
OD	1	81	235	1.06	0.09	1.16	0.97	81	231	0.81	0.32	1.14	0.49
OD	2	4	274	1.22	-0.31	0.91	1.53	4	275	1.39	-0.26	1.13	1.65
OD	2	31	281	1.23	0.26	1.49	0.96	31	275	1.34	0.27	1.61	1.07
OD	2	58	255	1.07	0.09	1.17	0.98	58	256	1.08	0.13	1.21	0.95
OD	3	4	281	1.20	-0.38	0.81	1.58	4	276	1.36	-0.19	1.17	1.56
OD	3	20	280	1.32	0.00	1.32	1.31	20	273	1.29	0.02	1.31	1.27
OD	3	37	266	1.12	0.09	1.21	1.02	37	257	1.02	0.08	1.11	0.93
RSC	2	4	295	0.89	-0.13	0.76	1.03	4	289	0.61	-0.09	0.51	0.71
RSC	2	24	287	0.88	0.19	1.08	0.69	26	285	0.66	-0.01	0.65	0.67
RSC	2	44	270	0.50	0.12	0.62	0.37	49	296	0.37	0.07	0.45	0.30
OD	4	4	317	0.59	-0.06	0.52	0.66	4	315	0.45	-0.20	0.25	0.66
OD	4	42	311	0.55	0.21	0.76	0.33	42	299	0.48	0.23	0.72	0.24
OD	4	80	299	0.40	0.04	0.44	0.35	80	289	0.20	0.08	0.29	0.11
CC	2	4	125	0.78	-0.08	0.70	0.86	4	129	0.72	-0.07	0.65	0.79
CC	2	22	128	0.80	0.19	1.00	0.60	27	125	0.66	0.01	0.67	0.65
CC	2	41	88	0.43	0.12	0.55	0.31	50	104	0.50	0.08	0.59	0.41
BC	2	4	145	0.31	-0.11	0.20	0.42	4	145	0.39	-0.03	0.36	0.43
BC	2	23	133	0.10	0.01	0.12	0.08	23	116	0.11	0.01	0.13	0.09
BC	2	42	118	0.10	0.00	0.10	0.09	42	128	0.08	0.00	0.08	0.08
BC	4	4	88	0.27	0.00	0.27	0.26	4	104	0.34	-0.03	0.31	0.37
BC	4	21	65	0.24	0.04	0.29	0.19	27	62	0.10	0.03	0.14	0.07
BC	4	37	63	0.21	0.05	0.26	0.16	50	59	0.11	0.03	0.15	0.07
FM	1	4	70	0.08	0.00	0.09	0.08	4	65	0.09	-0.02	0.07	0.11
FM	1	22	76	0.09	0.00	0.09	0.09	26	102	0.09	0.03	0.12	0.06
FM	1	40	90	0.16	0.06	0.23	0.10	48	90	0.07	0.00	0.08	0.06

* Maximum flood and ebb velocities are the peak values of the cosine curve fit of the data rather than the peak observed values.

Table 7

Plan Minus Base Velocity Characteristics Differences*

During Spring Tide, 120,000-cfs Inflow Test

Range	Station	Depth** ft	Phase deg	Amplitude fps	Offset fps	Maximum Velocity, fps† Flood	Maximum Velocity, fps† Ebb
CPH	1	4	28	-0.18	-0.13	-0.31	-0.04
CPH	1	23	-2	-0.14	0.15	0.00	-0.29
CPH	1	42	3	0.16	0.00	0.16	0.15
YSC	1	4	0	-0.61	0.20	-0.40	-0.82
YSC	1	24	3	0.09	0.08	0.17	0.00
YSC	1	45	4	0.46	0.46	0.93	0.00
CB-1	5	4	-0	-0.25	-0.10	-0.36	-0.15
CB-1	5	22	-11	0.02	0.16	0.19	-0.14
CB-1	5	35	-4	-0.13	0.15	0.02	-0.28
YSC	4	4	2	-0.04	-0.03	-0.07	-0.01
YSC	4	22	1	-0.11	0.11	-0.00	-0.23
YSC	4	40	0	0.00	0.33	0.33	-0.32
OD	1	4	4	0.03	0.12	0.15	-0.09
OD	1	42	-1	0.05	-0.05	-0.00	0.11
OD	1	81	4	0.19	-0.17	0.01	0.37
OD	2	4	-1	-0.12	0.04	-0.08	-0.16
OD	2	31	-4	-0.08	0.01	-0.07	-0.09
OD	2	58	-0	0.14	0.03	0.17	0.10
OD	3	4	-1	-0.10	0.07	-0.03	-0.17
OD	3	20	-1	-0.05	-0.04	-0.10	-0.01
OD	3	37	2	-0.12	0.03	-0.09	-0.16
RSC	2	4	50	-0.23	0.11	-0.12	-0.35
RSC	2	24	45	-0.37	0.02	-0.35	-0.40
RSC	2	44	53	-0.35	-0.04	-0.39	-0.30
OD	4	4	53	-0.19	0.09	-0.10	-0.28
OD	4	42	66	0.02	-0.09	-0.07	0.11
OD	4	80	9	-0.09	0.04	-0.04	-0.14
CC	2	4	-7	-0.28	0.13	-0.15	-0.42
CC	2	22	5	-0.15	0.07	-0.08	-0.22
CC	2	41	16	-0.14	0.01	-0.12	-0.15
BC	2	4	-2	-0.14	0.04	-0.10	-0.19
BC	2	23	(13)	-0.04	-0.03	-0.07	-0.01
BC	2	42	(66)	-0.16	-0.06	-0.22	-0.09
BC	4	4	34	-0.00	-0.11	-0.12	0.11
BC	4	21	66	-0.06	0.03	-0.03	-0.10
BC	4	37	10	0.03	-0.14	-0.11	0.18
FM	1	4	(-15)	0.04	-0.05	-0.00	0.10
FM	1	22	(-19)	-0.01	-0.00	-0.01	-0.01
FM	1	40	(44)	-0.10	0.00	-0.09	-0.10

* All differences are expressed as plan value minus base value.

** Base test depth; see Table 2 for plan test depth.

† Maximum velocities determined from cosine curve fit of the data rather than the observed maximum values.

() Questionable value due to low currents.

Table 8

Plan Minus Base Velocity Characteristics Differences*

During Neap Tide, 120,000-cfs Inflow Test

Range	Station	Depth** ft	Phase deg	Amplitude fps	Offset fps	Maximum Velocity, fps† Flood	Ebb
CPH	1	4	-0	0.03	0.19	0.23	-0.16
CPH	1	23	-29	0.19	0.23	0.42	-0.04
CPH	1	42	8	0.21	-0.07	0.13	0.29
YSC	1	4	15	-0.14	0.25	0.11	-0.40
YSC	1	24	19	-0.18	0.27	0.09	-0.45
YSC	1	45	24	0.18	0.49	0.68	-0.30
CB-1	5	4	5	0.04	0.06	0.10	-0.01
CB-1	5	22	-10	0.12	0.13	0.25	-0.01
CB-1	5	35	-2	0.20	0.21	0.41	-0.01
YSC	4	4	9	-0.20	0.08	-0.11	-0.28
YSC	4	22	10	-0.22	0.17	-0.05	-0.40
YSC	4	40	-14	0.24	0.42	0.67	-0.18
OD	1	4	1	0.07	-0.10	-0.03	0.17
OD	1	42	-3	-0.10	0.03	-0.07	-0.14
OD	1	81	-0	0.10	0.01	0.11	0.09
OD	2	4	-5	-0.04	-0.01	-0.05	-0.03
OD	2	31	-6	-0.01	0.03	0.01	-0.04
OD	2	58	-6	0.05	0.01	0.07	0.03
OD	3	4	-4	0.07	0.08	0.16	-0.01
OD	3	20	-6	0.09	0.04	0.13	0.04
OD	3	37	-4	-0.16	0.05	-0.11	-0.21
RSC	2	4	4	-0.14	0.01	-0.13	-0.15
RSC	2	24	-3	-0.20	0.12	-0.08	-0.32
RSC	2	44	26	-0.07	-0.04	-0.11	-0.03
OD	4	4	-0	0.15	-0.28	-0.12	0.44
OD	4	42	-14	0.08	-0.03	0.05	0.12
OD	4	80	(27)	0.03	-0.05	-0.01	0.09
CC	2	4	-30	-0.42	0.07	-0.35	-0.50
CC	2	22	-11	-0.01	0.14	0.12	-0.16
CC	2	41	-30	-0.35	-0.09	-0.44	-0.26
BC	2	4	4	0.09	-0.03	0.06	0.13
BC	2	23	(3)	0.01	0.00	0.01	0.00
BC	2	42	(-7)	0.01	-0.00	0.00	0.01
BC	4	4	-39	0.02	0.00	0.03	0.01
BC	4	21	-16	0.03	0.06	0.10	-0.02
BC	4	37	-28	-0.04	0.01	-0.02	-0.05
FM	1	4	(-53)	0.01	-0.00	0.00	0.01
FM	1	22	(4)	-0.09	0.03	-0.05	-0.12
FM	1	40	(32)	-0.00	0.01	0.01	-0.02

* All differences are expressed as plan value minus base value.

** Base test depth; see Table 2 for plan test depth.

† Maximum velocities determined from cosine curve fit of the data rather than the observed maximum values.

() Questionable value due to low currents.

Table 9

Plan Minus Base Velocity Characteristics Differences*

During Spring Tide, 30,000-cfs Inflow Test

Range	Station	Depth** ft	Phase deg	Amplitude fps	Offset fps	Maximum Velocity, fps† Flood	Ebb
CPH	1	4	-2	-0.03	0.06	0.02	-0.09
CPH	1	23	-1	-0.08	0.02	-0.05	-0.10
CPH	1	42	6	0.19	-0.02	0.17	0.21
YSC	1	4	3	-0.34	0.33	-0.00	-0.68
YSC	1	24	2	0.08	0.17	0.26	-0.09
YSC	1	45	7	0.50	0.29	0.80	0.20
CB-1	5	4	1	0.17	0.08	0.26	0.08
CB-1	5	22	1	0.46	0.19	0.65	0.26
CB-1	5	35	-4	0.20	0.20	0.40	0.00
YSC	4	4	-0	-0.32	0.18	-0.14	-0.51
YSC	4	22	-4	-0.05	0.06	0.00	-0.11
YSC	4	40	2	-0.15	-0.08	-0.24	-0.07
OD	1	4	0	-0.04	0.10	0.06	-0.15
OD	1	42	0	-0.27	-0.08	-0.36	-0.19
OD	1	81	1	0.14	-0.12	0.02	0.26
OD	2	4	-3	-0.15	0.06	-0.09	-0.21
OD	2	31	-2	-0.23	-0.08	-0.32	-0.15
OD	2	58	4	-0.26	-0.02	-0.28	-0.23
OD	3	4	-2	0.22	-0.13	0.08	0.36
OD	3	20	1	0.36	0.14	0.50	0.21
OD	3	37	-1	0.10	-0.00	0.10	0.11
RSC	2	4	9	-0.09	0.13	0.03	-0.22
RSC	2	24	9	-0.26	-0.03	-0.30	-0.23
RSC	2	44	-2	-0.26	0.06	-0.20	-0.32
OD	4	4	6	0.28	-0.02	0.26	0.30
OD	4	42	-5	0.22	0.04	0.27	0.17
OD	4	80	-15	-0.03	-0.03	-0.07	0.00
CC	2	4	7	-0.18	-0.08	-0.26	-0.09
CC	2	22	-1	-0.11	0.18	0.06	-0.30
CC	2	41	9	-0.23	-0.09	-0.33	-0.13
BC	2	4	-9	-0.22	0.00	-0.22	-0.22
BC	2	23	(-1)	-0.01	0.01	0.00	-0.03
BC	2	42	(-39)	0.02	-0.02	-0.00	0.05
BC	4	4	-25	-0.06	0.08	0.01	-0.15
BC	4	21	-40	-0.00	0.03	0.02	-0.03
BC	4	37	11	0.09	-0.17	-0.08	0.26
FM	1	4	(3)	-0.07	0.01	-0.06	-0.08
FM	1	22	(-1)	-0.04	0.04	-0.00	-0.09
FM	1	40	(10)	0.02	0.00	0.02	0.01

* All differences are expressed as plan value minus base value.

** Base test depth; see Table 2 for plan test depth.

† Maximum velocities determined from cosine curve fit of the data rather than the observed maximum values.

() Questionable value due to low currents.

Table 10

Plan Minus Base Velocity Characteristics Differences*

During Neap Tide, 30,000-cfs Inflow Test

Range	Station	Depth** ft	Phase deg	Amplitude fps	Offset fps	Maximum Velocity, fps† Flood	Ebb
CPH	1	4	-18	-0.44	0.38	-0.05	-0.82
CPH	1	23	-8	-0.09	0.14	0.05	-0.23
CPH	1	42	8	-0.06	0.02	-0.04	-0.08
YSC	1	4	5	-0.21	0.41	0.20	-0.62
YSC	1	24	6	0.03	0.05	0.08	-0.02
YSC	1	45	9	0.15	0.32	0.48	-0.17
CB-1	5	4	-2	-0.23	0.20	-0.03	-0.44
CB-1	5	22	-1	-0.23	0.01	-0.21	-0.24
CB-1	5	35	-4	-0.36	0.14	-0.21	-0.51
YSC	4	4	3	-0.02	0.18	0.16	-0.21
YSC	4	22	-10	-0.05	0.13	0.08	-0.18
YSC	4	40	9	0.08	0.04	0.13	0.03
OD	1	4	-6	0.11	0.22	0.33	-0.10
OD	1	42	-0	0.13	-0.01	0.12	0.15
OD	1	81	-3	-0.24	0.22	-0.02	-0.47
OD	2	4	1	0.16	0.04	0.21	0.11
OD	2	31	-5	0.11	0.00	0.12	0.11
OD	2	58	0	0.00	0.03	0.03	-0.03
OD	3	4	-5	0.16	0.19	0.36	-0.02
OD	3	20	-6	-0.02	0.01	-0.00	-0.03
OD	3	37	-8	-0.09	-0.00	-0.10	-0.09
RSC	2	4	-5	-0.28	0.04	-0.24	-0.32
RSC	2	24	-1	-0.22	-0.20	-0.42	-0.02
RSC	2	44	26	-0.12	-0.05	-0.17	-0.07
OD	4	4	-1	-0.13	-0.13	-0.27	0.00
OD	4	42	-12	-0.06	0.02	-0.04	-0.08
OD	4	80	(-9)	-0.19	0.04	-0.14	-0.24
CC	2	4	3	-0.06	0.01	-0.05	-0.07
CC	2	22	-3	-0.14	-0.18	-0.32	0.04
CC	2	41	15	0.07	-0.03	0.03	0.10
BC	2	4	-0	0.08	0.07	0.16	0.01
BC	2	23	(-17)	0.01	0.00	0.01	0.01
BC	2	42	(9)	-0.02	-0.00	-0.02	-0.01
BC	4	4	15	0.07	-0.03	0.03	0.11
BC	4	21	(-3)	-0.13	-0.01	-0.15	-0.11
BC	4	37	(-3)	-0.10	-0.01	-0.11	-0.08
FM	1	4	(-4)	0.00	-0.02	-0.01	0.03
FM	1	22	(26)	-0.00	0.03	0.02	-0.03
FM	1	40	(-0)	-0.09	-0.05	-0.14	-0.03

* All differences are expressed as plan value minus base value.
** Base test depth; see Table 2 for plan test depth.
† Maximum velocities determined from cosine curve fit of the data rather than the observed maximum values.
() Questionable value due to low currents.

Table 11

Velocity Phase Difference,* Frequency-of-Occurrence Summary, All Tests

Range and Station	Number of Observations/Degree Interval						
	$x < -30$	$-30 \le x < -20$	$-20 \le x < -10$	$-10 \le x \le 10$	$10 < x \le 20$	$20 < x \le 30$	$x > 30$
CPH-1		1	1	9		1	
YSC-1				9	3	1	
CB-1-5			1	11			
YSC-4			1	10	1		
OD-1				12			
OD-2				12			
OD-3				12			
RSC-2				7		2	3
OD-4			3	5 (1)**		(1)	2
CC-2		2	1	7	2		
BC-2	(1)		(1)	4 (4)	(1)		(1)
BC-4	2	2	1	2 (2)	1		2
FM-1	(1)		(2)	(5)	(1)	(1)	(2)
Total Observations	2	5	8	100	6	4	7
Percent	1.5	3.8	6.1	75.8	4.5	3.0	5.3

Note: $-10 \le x \le 10$, 75.8 percent; $-20 \le x \le 20$, 86.4 percent; $-30 \le x \le 30$, 93.2 percent.

* 10 deg approximately equals 20 min prototype time.

** ( ) denote questionable values; not considered in frequency of occurrence or percentage.

Table 12

Velocity Amplitude Difference, Frequency-of-Occurrence Summary, All Tests

Range and Station	Number of Observations/fps Interval: $x < -0.40$	$-0.40 \le x < -0.25$	$-0.25 \le x < -0.10$	$-0.10 \le x \le 0.10$	$0.10 < x \le 0.25$	$0.25 < x \le 0.40$	$x > 0.40$
CPH-1	1		2	5	4		
YSC-1	1	1	3	3	2		2
CB-1-5		2	3	2	4		1
YSC-4		1	4	6	1		
OD-1		1	1	4	6		
OD-2		1	3	5	3		
OD-3			2	6	3	1	
RSC-2		5	5	2			
OD-4			3	6	2	1	
CC-2	1	2	6	3			
BC-2			3	9			
BC-4			1	11			
FM-1				12			
Total Observations	3	13	36	74	25	2	3
Percent	1.9	8.3	23.1	47.4	16.0	1.3	1.9

Note: $-0.10 \le x \le 0.10$, 47.4 percent; $-0.25 \le x \le 0.25$, 86.5 percent; $-0.40 \le x \le 0.40$, 96.1 percent.

Table 13

Velocity Offset Difference, Frequency-of-Occurrence Summary, All Tests

Range and Station	Number of Observations/fps Interval						
	$x < -0.40$	$-0.40 \le x < -0.25$	$-0.25 \le x < -0.10$	$-0.10 \le x \le 0.10$	$0.10 < x \le 0.25$	$0.25 < x \le 0.40$	$x > 0.40$
CPH-1			1	6	4	1	
YSC-1				2	2	5	3
CB-1-5				4	8		
YSC-4				5	5	1	1
OD-1			2	6	4		
OD-2				12			
OD-3			1	9	2		
RSC-2				8	4		
OD-4		1	1	10			
CC-2			1	8	3		
BC-2				12			
BC-4			3	9			
FM-1				12			
Total Observations		1	9	103	32	7	4
Percent		0.6	5.8	66	20.5	4.5	2.6

Note: $-0.10 \le x \le 0.10$, 66 percent; $-0.25 \le x \le 0.25$, 92.3 percent; $-0.40 \le x \le 0.40$, 97.4 percent.

Table 14

Maximum Flood Velocity Difference,* Frequency-of-Occurrence Summary, All Tests

Range and Station	Number of Observations/fps Interval						
	$X < -0.40$	$-0.40 \le x < -0.25$	$-0.25 \le x < -0.10$	$-0.10 \le x \le 0.10$	$0.10 < x \le 0.25$	$0.25 < x \le 0.40$	$x > 0.40$
CPH-1		1		6	4		1
YSC-1	1			3	3	1	4
CB-1-5		1	2	2	2	2	3
YSC-4			3	5	2	1	1
OD-1		1		7	3	1	
OD-2		2		7	3		
OD-3			2	5	3	1	1
RSC-2	1	3	6	2			
OD-4		1	3	6		2	
CC-2	1	4	2	4	1		
BC-2			2	9	1		
BC-4			4	8			
FM-1			1	11			
Total Observations	3	13	25	75	22	8	10
Percent	1.9	8.3	16.0	48.1	14.1	5.1	6.4

Note: $-0.10 \le x \le 0.10$, 48.1 percent; $-0.25 \le x \le 0.25$, 78.2 percent; $-0.40 \le x \le 0.40$, 91.6 percent.

* All Differences are expressed as plan value minus base value. Maximum velocities determined from cosine curve fit of the data rather than the observed maximum values.

Table 15

Maximum Ebb Velocity Difference,* Frequency-of-Occurrence Summary, All Tests

Range and Station	Number of Observations/fps Interval						
	$x < -0.40$	$-0.40 \le x < -0.25$	$-0.25 \le x < -0.10$	$-0.10 \le x \le 0.10$	$0.10 < x \le 0.25$	$0.25 < x \le 0.40$	$x > 0.40$
CPH-1	1	1	3	4	2	1	
YSC-1	5	1	1	4	1		
CB-1-5	2	1	3	5		1	
YSC-4	2	2	5	3			
OD-1	1		4	2	3	2	
OD-2			4	6	2		
OD-3			3	6	2	1	
RSC-2	1	5	3	3			
OD-4		2	2	4	2	1	1
CC-2	2	2	5	3			
BC-2			2	9	1		
BC-4			2	6	3	1	
FM-1			1	11			
Total Observations	14	14	38	56	16	7	1
Percent	9.0	9.0	24.3	42.3	10.3	4.5	0.6

Note: $-0.10 \le x \le 0.10$, 48.1 percent; $-0.25 \le x \le 0.25$, 78.2 percent; $-0.40 \le x \le 0.40$, 91.6 percent.

* All Differences are expressed as *plan value minus base value*. *Maximum* velocities determined *from* cosine curve fit of the data rather than the observed maximum values.

Table 16

Total Bay Freshwater Discharge Hydrograph

Last Half of Water Year 1964			Water Year 1965						Modal Year					
Hydrograph Step	Prototype Week	Total cfs	Hydrograph Step	Prototype Week	Total cfs	Hydrograph Step	Prototype Week	Total cfs	Hydrograph Step	Prototype Week	Total cfs	Hydrograph Step	Prototype Week	Total cfs
1	28	129,950	26	1	17,966	51	26	192,236	78	1	28,479	104	27	168,737
2	29	125,775	27	2	12,391	52	27	105,951	79	2	33,917	105	28	150,410
3	30	163,400	28	3	14,102	53	28	111,468	80	3	38,501	106	29	133,429
4	31	218,936	29	4	12,552	54	29	107,999	81	4	42,910	107	30	119,483
5	32	81,639	30	5	9,673	55	30	101,311	82	5	47,411	108	31	105,766
6	33	56,374	31	6	9,391	56	31	34,818	83	6	51,979	109	32	97,340
7	34	33,950	32	7	9,175	57	32	67,896	84	7	56,673	110	33	90,069
8	35	24,069	33	8	12,226	58	33	51,402	85	8	61,196	111	34	83,248
9	36	24,932	34	9	29,661	59	34	34,423	86	9	65,773	112	35	78,003
10	37	21,480	35	10	23,572	60	35	30,302	87	10	70,239	113	36	73,175
11	38	19,502	36	11	30,492	61	36	27,748	88	11	73,254	114	37	68,318
12	39	15,468	37	12	26,959	62	37	22,716	89	12	75,783	115	38	63,607
13	40	11,952	38	13	44,134	63	38	20,687	90	13	77,799	116	39	58,936
14	41	19,208	39	14	49,477	64	39	13,744	91	14	79,228	117	40	54,780
15	42	15,641	40	15	64,377	65	40	12,179	92	15	80,815	118	41	50,280
16	43	12,546	41	16	47,161	66	41	19,102	93	16	83,493	119	42	46,779
17	44	11,948	42	17	78,338	67	42	16,847	94	17	86,658	120	43	43,310
18	45	14,131	43	18	61,560	68	43	10,186	95	18	89,753	121	44	39,987
19	46	10,387	44	19	117,437	69	44	14,395	96	19	96,060	122	45	36,612
20	47	7,527	45	20	138,790	70	45	13,199	97	20	103,655	123	46	33,347
21	48	9,732	46	21	70,910	71	46	8,930	98	21	113,496	124	47	30,207
22	49	10,285	47	22	79,061	72	47	10,431	99	22	129,703	125	48	27,051
23	50	6,706	48	23	178,063	73	48	15,182	100	23	146,316	126	49	24,131
24	51	6,510	49	24	93,559	74	49	9,653	101	24	161,333	127	50	21,904
25	52	8,144	50	25	85,493	75	50	9,927	102	25	172,538	128	51	20,462
						76	51	11,992	103	26	181,175	129	52	23,780
						77	52	11,993						

Table 17

Salinity Station and Sampling Depths

Location	Station	Depth, ft Base	Depth, ft Plan
CB-0-1	1-59	7	7
		20	20
		52	52
CB-0-2	2-63	4	4
		20	20
		52	52
CB-0-3	3-42	4	4
		12	12
		33	33
CPH-1	4-*	4	4
		23	23
		46	52
CPH-2	5-*	4	4
		25	25
		50	50
YSC-1	6-*	4	4
		24	24
		49	49
YSC-2	7-*	4	4
		22	22
		44	52
CB-1-5	8-*	4	4
		21	21
		35	43
YSC-3	9-*	4	4
		22	22
		44	53
YSC-4	10-*	2	2
		22	22
		44	52
YSC-5	11-*	4	4
		24	24
		49	53

Location	Station	Depth, ft Base	Depth, ft Plan
CB-1-7	12-28	3	3
		12	12
		26	26
CB-1-2	13-22	4	4
		10	10
		19	19
J-1-2	14-52	1	1
		23	23
		43	43
J-1-3	15-81	1	1
		13	13
		23	23
		43	43
		72	72
Y-1-1	16-37	3	3
		23	23
		33	33
Y-1-2	17-56	5	5
		15	15
		25	25
		35	35
		54	54
MB-1-1	18-16	0	0
		13	13
MB-1-3	19-20	0	0
		7	7
		13	13
CB-2-3	20-33	4	4
		11	11
		29	29
CB-2-5	21-38	4	4
		12	12
		32	32
CB-2-7	22-48	4	4
		20	20
		39	39

Location	Station	Depth, ft Base	Depth, ft Plan
R-1-1	23-30	1	1
		13	13
		30	30
R-1-2	24-36	1	1
		13	13
		33	33
RSC-1	25-*	4	4
		24	24
		49	53
RSC-2	26-*	4	4
		24	24
		48	53
RSC-3	27-*	4	4
		23	23
		47	54
CB-3-4	78-71	4	4
		12	12
		22	22
		32	32
		41	41
CB-3-6	29-42	4	4
		23	23
		38	38
CB-3-8	30-27	4	4
		13	13
		19	19
PO-1-1	31-28	2	2
		12	12
		22	22
PO-1-3	32-42	2	2
		22	22
		40	40
PO-1-5	33-32	2	2
		22	22
		31	31

Location	Station	Depth, ft Base	Depth, ft Plan
CB-4-3	34-65	4	4
		33	33
		53	53
CB-4-4	35-103	4	4
		13	13
		34	34
		45	45
		52	52
CB-4-5	36-102	4	4
		12	12
		32	32
		42	42
		52	52
CB-5-2	37-37	4	4
		12	12
		33	33
CB-5-4	38-65	2	2
		22	22
		32	32
		42	42
		52	52
CB-5-5	39-109	31	31
		48	48
		37	37
		67	67
		76	76
CB-5-6	40-25	4	4
		12	12
		19	19
CH-1-1	41-55	4	4
		22	22
		52	52
MA-1-1	42-21	4	4
		18	18
CC-1	43-*	4	4
		23	23
		45	53

Location	Station	Depth, ft Base	Depth, ft Plan
CC-2	44-*	4	4
		22	22
		45	52
CC-3	45-*	4	4
		22	22
		45	52
PR-1-3	46-*	2	2
		22	22
		38	54
BC-3	47-*	4	4
		21	21
		43	52
BC-4	48-*	4	4
		21	21
		42	52
PR-2-2	49-*	2	2
		12	12
		41	52
PR-3-1/ FM-1	50-*	4	4
		22	22
		41	53
FM-2	51-*	4	4
		21	21
		43	52
EC-1	52-*	4	4
		17	17
		34	50
FB-1	53-*	4	4
		20	20
		41	41
CBC-1	54-*	4	4
		16	16
		33	46
PR-2-1	55-17	2	2
		14	14

Location	Station	Depth, ft Base	Depth, ft Plan
SP-1	56-33	4	4
		16	16
		32	32
PR-1-2	57-17	2	2
		14	14
PR-1-1	58-16	2	2
		14	14
BC-2	59-47	4	4
		23	23
		46	46
BC-1	60-44	4	4
		21	21
		43	43
CB-6-1	61-22	2	2
		20	20
CB-6-3	62-33	2	2
		12	12
		31	31
CB-6-4	63-37	2	2
		21	21
		35	35
CB-6-5	64-20	2	2
		18	18
CB-7-1	65-15	6	6
		12	12
CB-7-3	66-34	2	2
		12	12
		24	24
CB-7-4	67-24	2	2
		12	12
		24	24
CB-7-5	68-47	2	2
		27	27
		46	46

Note: Under second column, Station, "1-59," - 1 is identification number, 59 is total depth in feet, etc.
* Depth deepened before plan test.

Table 18

Percent Frequency of Occurrence Summary

Station	Depth	Percent Frequency of Occurrence for Cited Salinity Difference Intervals											Number of Observations
		$x < -10$	$-10 \le x < -5$	$-5 \le x < -3$	$-3 \le x < -2$	$-2 \le x < -1$	$-1 \le x \le 1$	$1 < x \le 2$	$2 < x \le 3$	$3 < x \le 5$	$5 < x \le 10$	$x > 10$	
CB-0-1	Surface			1.3	2.7	1.3	58.7	28.0	5.3	2.7			75
	Middepth				2.7	1.3	84.0	10.7			1.3		75
	Bottom					5.7	87.1	5.7	1.4				70
CB-0-2	Surface			1.4	4.1	2.7	52.7	27.0	8.1	2.7	1.4		74
	Middepth				1.4	2.7	87.8	6.8			1.4		74
	Bottom					2.7	94.6	2.7					74
CB-0-3	Surface		1.4		1.4	4.1	79.7	10.8	2.7				74
	Middepth				2.7	2.7	85.1	9.5					74
	Bottom					2.7	96.0	1.3					75
CPH-1	Surface					2.7	75.7	18.9	2.7				74
	Middepth						96.0	2.7		1.3			75
	Bottom						97.3	1.3		1.3			75
CPH-2	Surface				4.2	18.3	73.2	4.2					71
	Middepth					7.0	88.7	1.4	1.4		1.4		71
	Bottom					2.8	95.8	1.4					71
YSC-1	Surface		1.4		2.7	6.8	58.9	15.1	8.2	6.8			73
	Middepth				4.1	5.5	75.3	13.7		1.4			73
	Bottom				1.4	4.1	86.3	6.8	1.4				73
YSC-2	Surface					2.7	35.6	45.2	13.7	2.7			73
	Middepth				1.4	5.7	65.7	21.4	4.3	1.4			70
	Bottom				1.4	6.9	81.9	5.6	1.4	1.4	1.4		72
CB-1-5	Surface				2.7	4.1	77.0	13.5	2.7				74
	Middepth					5.4	86.5	6.8	1.4				74
	Bottom				1.4	2.8	76.4	16.7	1.4		1.4		72
YSC-3	Surface				4.2	1.4	44.4	33.3	16.7				72
	Middepth					11.0	82.2	6.8					73
	Bottom					2.8	80.3	15.5	1.4				71
YSC-4	Surface					1.4	57.7	36.6	4.2				71
	Middepth						73.2	26.8					71
	Bottom						82.6	13.0	2.9	1.4			69
YSC-5	Surface					1.4	67.1	22.9	8.6				70
	Middepth					7.1	82.9	10.0					70
	Bottom					4.2	77.8	12.5	4.2	1.4			72

(Continued)

Table 18 (Continued)

Station	Depth	Percent Frequency of Occurrence for Cited Salinity Difference Intervals											Number of Observations
		x < -10	-10 ≤ x < -5	-5 ≤ x < -3	-3 ≤ x < -2	-2 ≤ x < -1	-1 ≤ x ≤ 1	1 < x ≤ 2	2 < x ≤ 3	3 < x ≤ 5	5 < x ≤ 10	x > 10	
CB-1-2	Surface					2.8	79.2	18.1					72
	Middepth					1.4	78.4	18.9	1.4				74
	Bottom				1.4	1.4	83.8	13.5					74
CB-1-7	Surface					1.4	68.1	23.6	5.6	1.4			72
	Middepth						73.0	23.0	4.1				74
	Bottom						86.3	13.7					73
J-1-2	Surface			2.8	1.4	8.3	61.1	22.2	1.4	2.8			72
	Middepth						67.1	32.9					73
	Bottom		1.4	1.4	7.1	21.4	60.0	7.1	1.4				70
J-1-3	Surface		1.4	1.4	5.7	10.0	67.1	11.4	2.9				70
	Middepth						78.6	21.4					70
	Bottom					13.4	79.1	4.5		1.5	1.5		67
Y-1-1	Surface				1.4	1.4	82.4	14.9					74
	Middepth						94.6	5.4					74
	Bottom						94.5	5.5					73
Y-1-2	Surface				2.9	7.2	73.9	14.5	1.4				69
	Middepth						93.1	6.9					72
	Bottom			9.6	11.0	16.4	58.9	1.4		2.7			73
MB-1-1	Surface				5.2	14.3	75.3	5.2					77
	Bottom						85.7	14.3					77
MB-1-3	Surface						50.0	50.0					4
	Middepth				1.3	1.3	58.7	33.3	4.0	1.3			75
	Bottom					1.3	63.2	35.5					76
CB-2-3	Surface					1.4	90.4	8.2					73
	Middepth					1.3	82.9	15.8					76
	Bottom					2.6	92.1	5.3					76
CB-2-5	Surface					2.7	81.1	12.2	4.1				74
	Middepth						6.8	39.2	47.3	6.8			74
	Bottom				1.4	1.4	79.5	15.1	2.7				73
CB-2-7	Surface					2.7	80.0	16.0	1.3				75
	Middepth					2.7	85.3	10.7		1.3			75
	Bottom				1.3	16.0	76.0	5.3		1.3			75

(Continued)

Table 18 (Continued)

Station	Depth	x < -10	-10 < x < -5	-5 < x < -3	-3 < x < -2	-2 < x < -1	-1 < x < 1	1 < x < 2	2 < x < 3	3 < x < 5	5 < x < 10	x > 10	Number of Observations
		Percent Frequency of Occurrence for Cited Salinity Difference Intervals											
R-1-1	Surface		1.3	1.3	2.6	7.8	74.0	10.4	2.6				77
	Middepth				1.4	2.7	75.3	17.8	2.7				73
	Bottom						89.3	9.3	1.3				75
R-1-2	Surface			1.3	1.3	5.3	86.7	5.3					75
	Middepth						88.6	11.4					70
	Bottom					1.4	88.7	9.9					71
RSC-1	Surface				1.6	3.2	87.1	8.1					62
	Middepth				1.8	5.3	80.7	12.3					57
	Bottom				3.4	11.9	76.3	6.8	1.7				59
RSC-2	Surface					3.3	80.3	16.4					61
	Middepth					1.5	69.2	29.2					65
	Bottom			1.6	3.1	10.9	78.1	4.7	1.6				64
RSC-3	Surface			3.1	3.1	9.4	76.6	6.3	1.6				64
	Middepth					4.5	89.4	6.1					66
	Bottom				6.2	7.7	86.2						65
CB-3-4	Surface				3.2	14.3	79.4	1.6		1.6			63
	Middepth					3.1	81.5	15.4					65
	Bottom					1.7	83.1	15.3					59
CB-3-6	Surface					3.1	87.5	9.4					64
	Middepth						82.5	17.5					63
	Bottom	1.5				1.5	74.2	22.7					66
CB-3-8	Surface						93.8	6.2					65
	Middepth						95.4	4.6					65
	Bottom						93.8	6.3					64
PO-1-1	Surface		1.4	4.2	5.6	11.3	40.8	25.4	9.9	1.4			71
	Middepth						74.6	23.9				1.4	71
	Bottom						81.7	18.3					71
PO-1-3	Surface		1.4	1.4	2.8	11.3	66.2	15.5		1.4			71
	Middepth					1.4	90.1	7.0	1.4				71
	Bottom					1.4	66.7	31.9					69
PO-1-5	Surface			4.3	11.6	13.0	68.1	2.9					69
	Middepth					1.4	84.1	14.5					69
	Bottom						73.1	26.9					67

(Continued)

Table 18 (Continued)

Station	Depth	x ≤ -10	-10 < x ≤ -5	-5 < x ≤ -3	-3 < x ≤ -2	-2 < x ≤ -1	-1 < x < 1	1 ≤ x < 2	2 ≤ x < 3	3 ≤ x < 5	5 ≤ x < 10	x ≥ 10	Number of Observations
		Percent Frequency of Occurrence for Cited Salinity Difference Intervals											
CB-4-3	Surface					20.3	73.9	5.8					69
	Middepth					1.5	94.1	4.4					68
	Bottom						85.3	14.7					68
CB-4-4	Surface					5.6	94.4						71
	Middepth					2.9	95.7	1.4					69
	Bottom						88.6	11.4					70
CB-4-5	Surface					4.5	94.0	1.5					67
	Middepth	1.4				1.4	94.3	2.9					70
	Bottom					1.4	85.5	13.0					69
CB-5-2	Surface			1.4	9.6	19.2	69.9						73
	Middepth					5.6	94.4						54
	Bottom	1.4					57.7	36.6	4.2				71
CB-5-4	Surface			1.5	4.6	4.6	73.8	13.8	1.5				65
	Middepth						51.4	37.5	11.1				72
	Bottom						34.8	40.6	21.7	2.9			69
CB-5-5	Surface						54.9	45.1					71
	Middepth						32.4	26.8	39.4	1.4			71
	Bottom						40.8	49.3	9.9				71
CB-5-6	Surface			1.5	10.4	14.9	64.2	4.5	1.5	3.0			67
	Middepth					4.2	77.5	8.5	8.5	1.4			71
	Bottom					2.9	75.4	11.6	10.1				69
MA-1	Surface			4.3	2.9	18.6	74.3						70
	Bottom			1.4	4.3	15.7	78.6						70
CH-1-1	Surface				1.5	6.0	47.8	37.3	7.5				67
	Middepth						61.4	34.3	4.3				70
	Bottom						41.4	48.6	10.0				70
CC-1	Surface		2.8	2.8	4.2	9.9	73.2	7.0					71
	Middepth					1.5	35.3	39.7	17.6	5.9			68
	Bottom				1.4		24.3	45.7	28.6				70
CC-2	Surface		2.9	5.9	17.6	33.8	39.7						68
	Middepth						22.5	32.4	26.8	18.3			71
	Bottom						16.9	40.8	38.0	4.2			71
CC-3	Surface			17.4	24.6	23.2	34.8						69
	Middepth						29.4	35.3	16.2	13.2	5.9		68
	Bottom						4.5	25.4	41.8	28.4			67

(Continued)

Table 18 (Continued)

Station	Depth	Percent Frequency of Occurrence for Cited Salinity Difference Intervals											Number of Observations
		$x < -10$	$-10 \le x < -5$	$-5 \le x < -3$	$-3 \le x < -2$	$-2 \le x < -1$	$-1 \le x \le 1$	$1 < x \le 2$	$2 < x \le 3$	$3 < x \le 5$	$5 < x \le 10$	$x > 10$	
PR-1-3	Surface		5.4	35.1	23.0	10.8	25.7						74
	Middepth					2.7	21.9	39.7	28.8	6.8			73
	Bottom							4.0	32.0	57.3	6.7		75
BC-3	Surface			4.2	5.6	5.6	36.6	36.6	11.3				71
	Middepth						21.4	20.0	37.1	21.4			70
	Bottom						2.8	9.7	41.7	45.8			72
BC-4	Surface		12.2	32.4	10.8	12.2	29.7	2.7					74
	Middepth						21.9	47.9	16.4	13.7			73
	Bottom						1.4	5.5	28.8	50.7	13.7		73
PR-2-2	Surface		1.3	26.3	19.7	15.8	32.9	3.9					76
	Middepth						18.7	33.3	29.3	18.7			75
	Bottom							2.8	11.3	26.8	56.3	2.8	71
PR-3-1/ FM-1	Surface		6.3	26.6	17.2	6.3	26.6	9.4	6.3	1.6			64
	Middepth					1.5	10.4	23.9	26.9	35.8	1.5		67
	Bottom							7.7	9.2	15.4	63.1	4.6	65
FM-2	Surface		2.9	1.5	1.5	5.9	32.4	8.8	29.4	17.6			68
	Middepth						7.6	21.2	28.8	42.4			66
	Bottom						4.4	13.2	11.8	30.9	38.2	1.5	68
EC-1	Surface			9.0	7.5	16.4	26.9	16.4	20.9	3.0			67
	Middepth						11.9	17.9	28.4	41.8			67
	Bottom						2.9	5.9	13.2	14.7	55.9	7.4	68
FB-1	Surface				4.5	4.5	22.4	20.9	34.3	13.4			67
	Middepth						7.2	20.3	34.8	37.7			69
	Bottom						7.2	15.9	27.5	29.0	20.3		69
CBC-1	Surface					1.5	10.4	13.4	29.9	43.3	1.5		67
	Middepth						7.6	16.7	37.9	37.9			66
	Bottom						1.5	6.2	20.0	16.9	53.8	1.5	65
PR-2-1	Surface		1.3	5.3	8.0	17.3	42.7	12.0	13.3				75
	Bottom						18.7	17.3	49.3	14.7			75
SP-1	Surface		1.3	9.3	17.3	10.7	50.7	9.3	1.3				75
	Middepth						28.2	42.3	26.8	2.8			71
	Bottom						17.3	10.7	28.0	28.0	16.0		75

(Continued)

Table 18 (Concluded)

Station	Depth	$x < -10$	$-10 \le x < -5$	$-5 \le x < -3$	$-3 \le x < -2$	$-2 \le x < -1$	$-1 \le x \le 1$	$1 < x \le 2$	$2 < x \le 3$	$3 < x \le 5$	$5 < x \le 10$	$x > 10$	Number of Observations
		Percent Frequency of Occurrence for Cited Salinity Difference Intervals											
PR-1-2	Surface			5.3	17.1	39.5	36.8		1.3				76
	Bottom						29.3	48.0	14.7	8.0			75
PR-1-1	Surface				8.1	23.0	66.2	2.7					74
	Bottom						26.7	46.7	17.3	9.3			75
BC-2	Surface			5.8	4.3	26.1	63.8						69
	Middepth						20.3	27.5	13.0	29.0	10.1		69
	Bottom						19.7	39.4	30.3	10.6			66
BC-1	Surface		1.6	3.1	9.4	21.9	64.1						64
	Middepth				1.6	3.1	25.0	35.9	10.9	18.8	4.7		64
	Bottom						31.7	42.9	22.2	3.2			63
CB-6-1	Surface		16.9	10.8	4.6	4.6	32.3	15.4	13.8	1.5			65
	Bottom						54.7	40.6	4.7				64
CB-6-3	Surface				4.5	16.7	66.7	9.1	3.0				66
	Middepth				1.6		89.1	7.8	1.6				64
	Bottom			1.5			54.5	31.8	12.1				66
CB-6-4	Surface			6.1	4.5	16.7	69.7	3.0					66
	Middepth						45.6	31.6	14.0	8.8			57
	Bottom						31.8	43.9	21.2	3.0			66
CB-6-5	Surface		1.5		7.7	24.6	66.2						65
	Bottom		1.5	1.5	1.5	1.5	58.5	24.6	4.6	4.6		1.5	65
CB-7-1	Surface			2.9	1.4	17.4	66.7	10.1	1.4				69
	Bottom			1.4	5.5	17.8	63.0	12.3					73
CB-7-3	Surface			2.8	2.8	14.1	73.2	5.6	1.4				71
	Middepth			2.7	5.5	6.8	72.6	12.3					73
	Bottom					5.6	45.8	23.6	9.7	11.1	4.2		72
CB-7-4	Surface			3.8		24.5	66.0	5.7					53
	Middepth		1.4	1.4	8.1	20.3	60.8	8.1					74
	Bottom		1.4	2.7	5.4	14.9	47.3	16.2	9.5	2.7			74
CB-7-5	Surface			2.7	2.7	13.5	73.0	8.1					74
	Middepth		1.3	2.7	1.3	10.7	61.3	14.7	8.0				75
	Bottom		1.3	2.7	1.3	5.3	50.7	18.7	10.7	6.7	2.7		75

(Sheet 6 of 6)

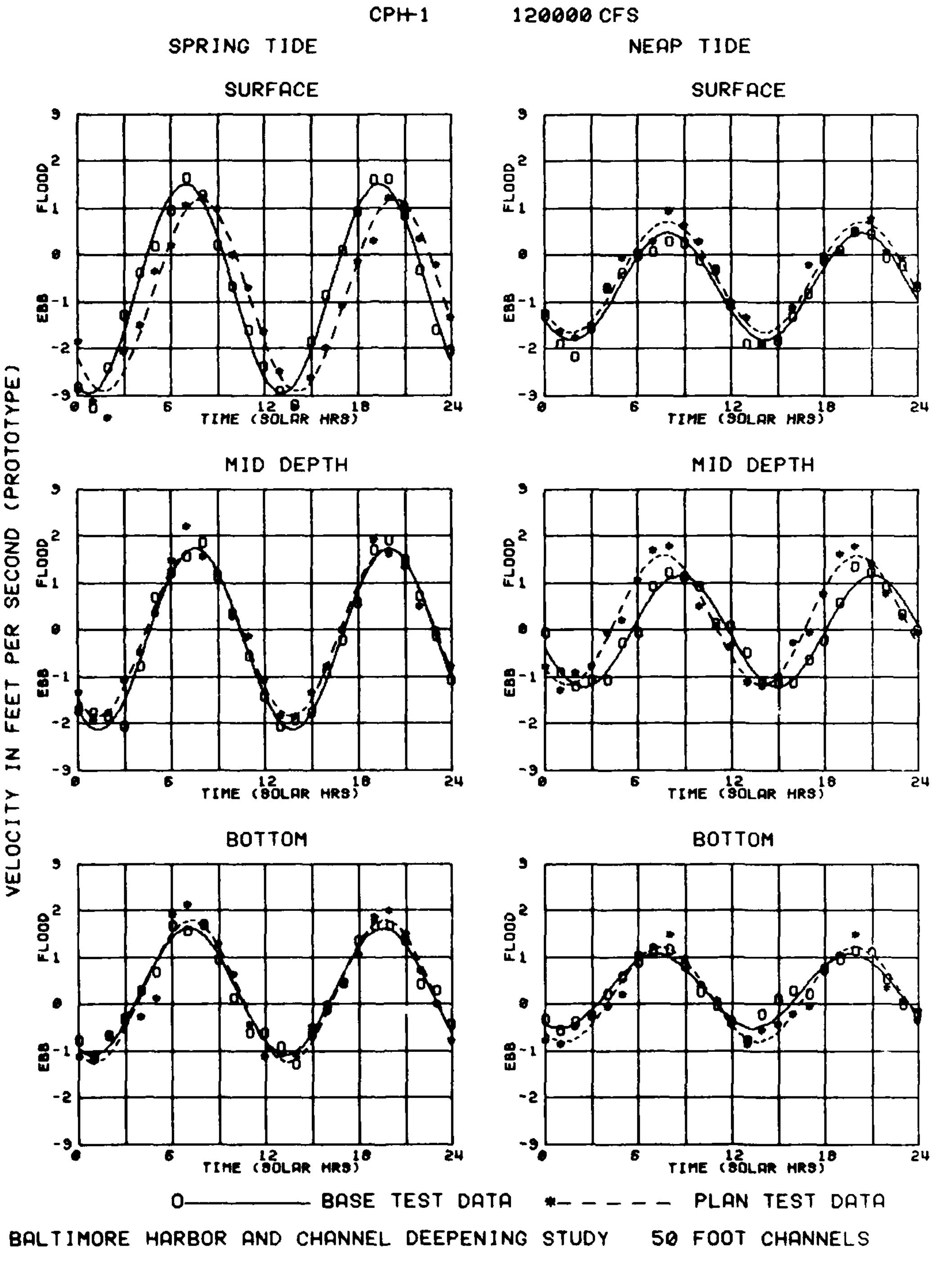


Plate 1. Sta CPH-1 velocity during 120,000-cfs tests

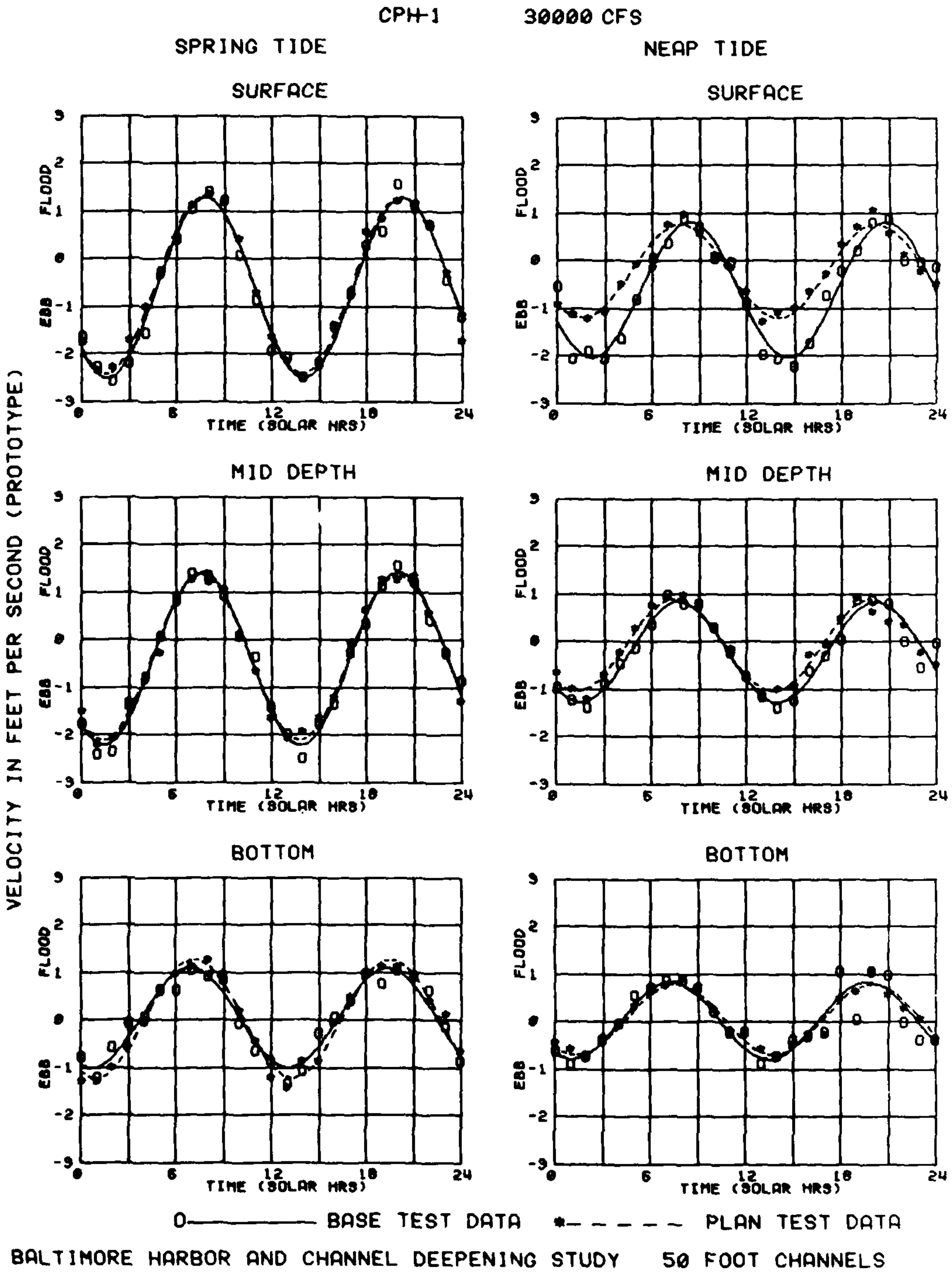


Plate 2. Sta CPH-1 velocity during 30,000-cfs tests

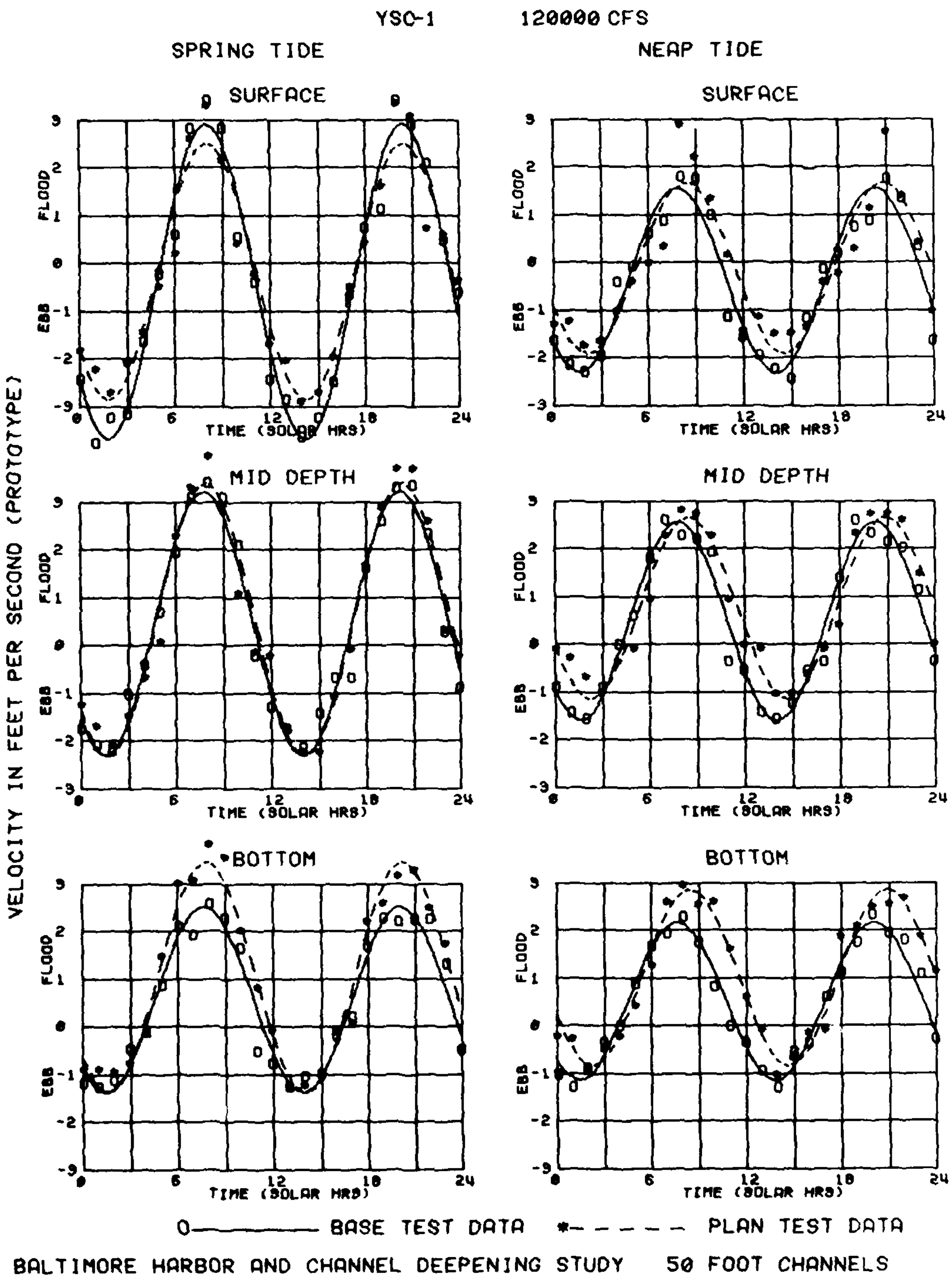


Plate 3. Sta YSC-1 velocity during 120,000-cfs tests

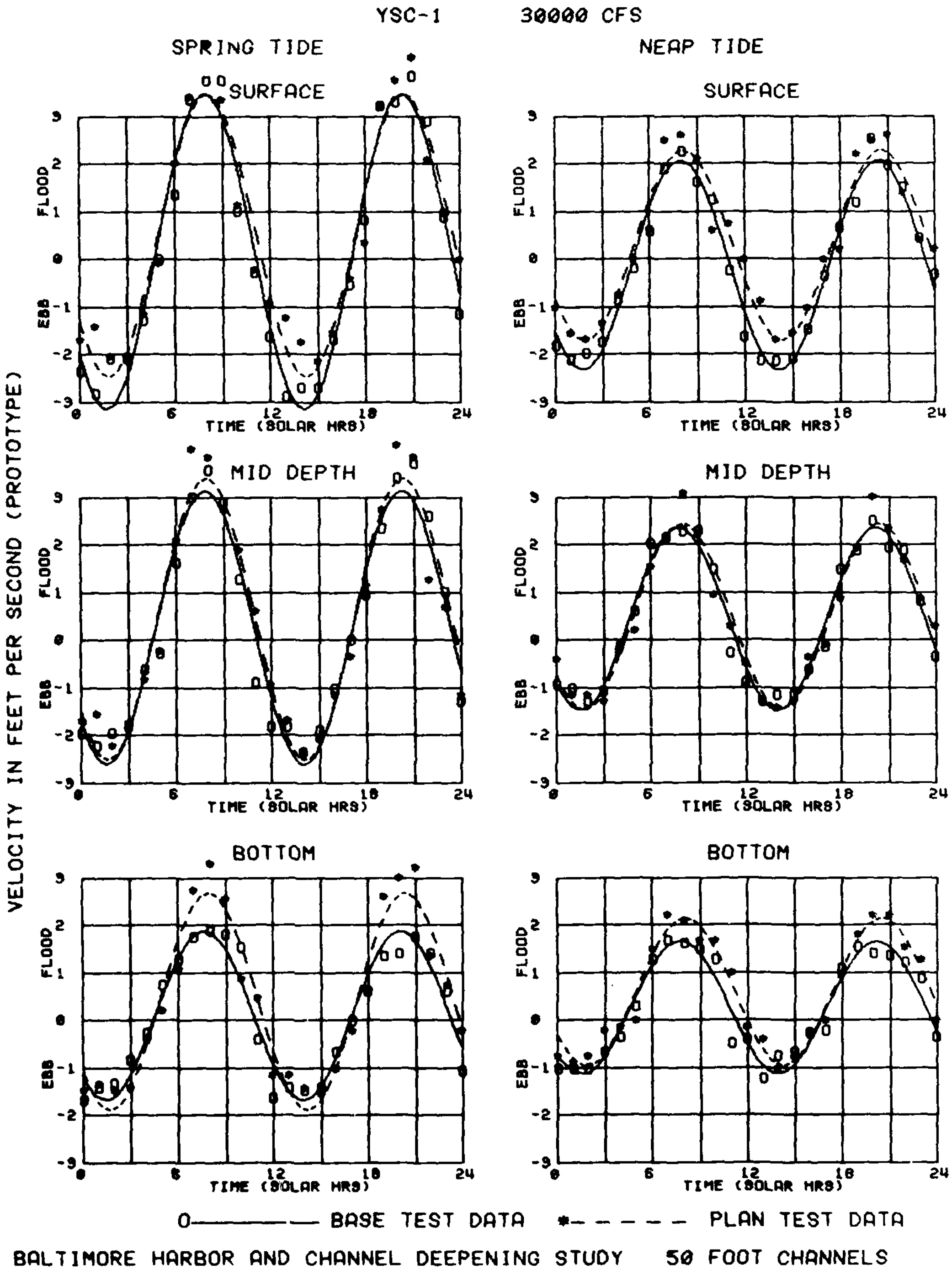


Plate 4. Sta YSC-1 velocity during 30,000-cfs tests

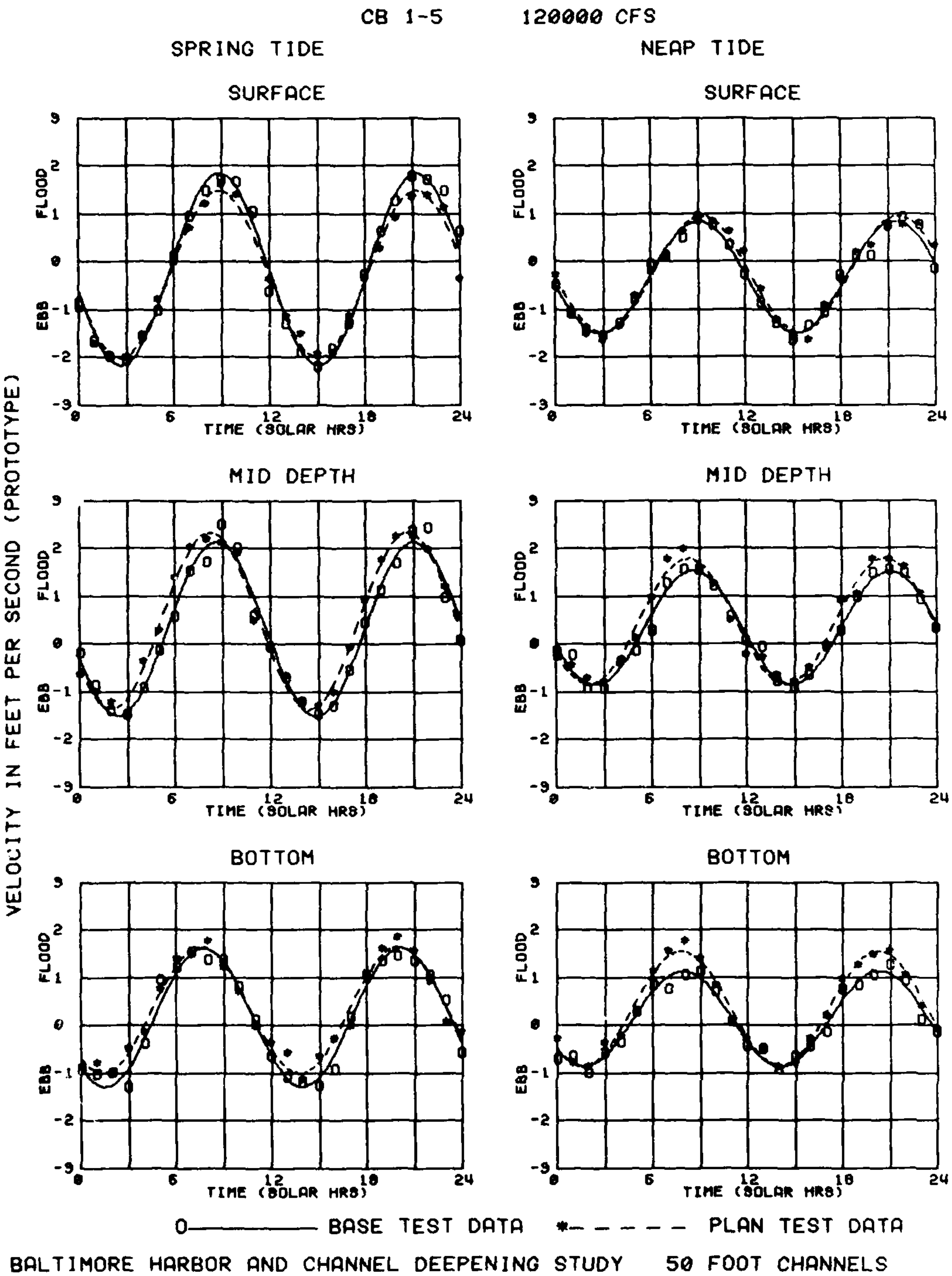


Plate 5. Sta CB-1-5 velocity during 120,000-cfs tests

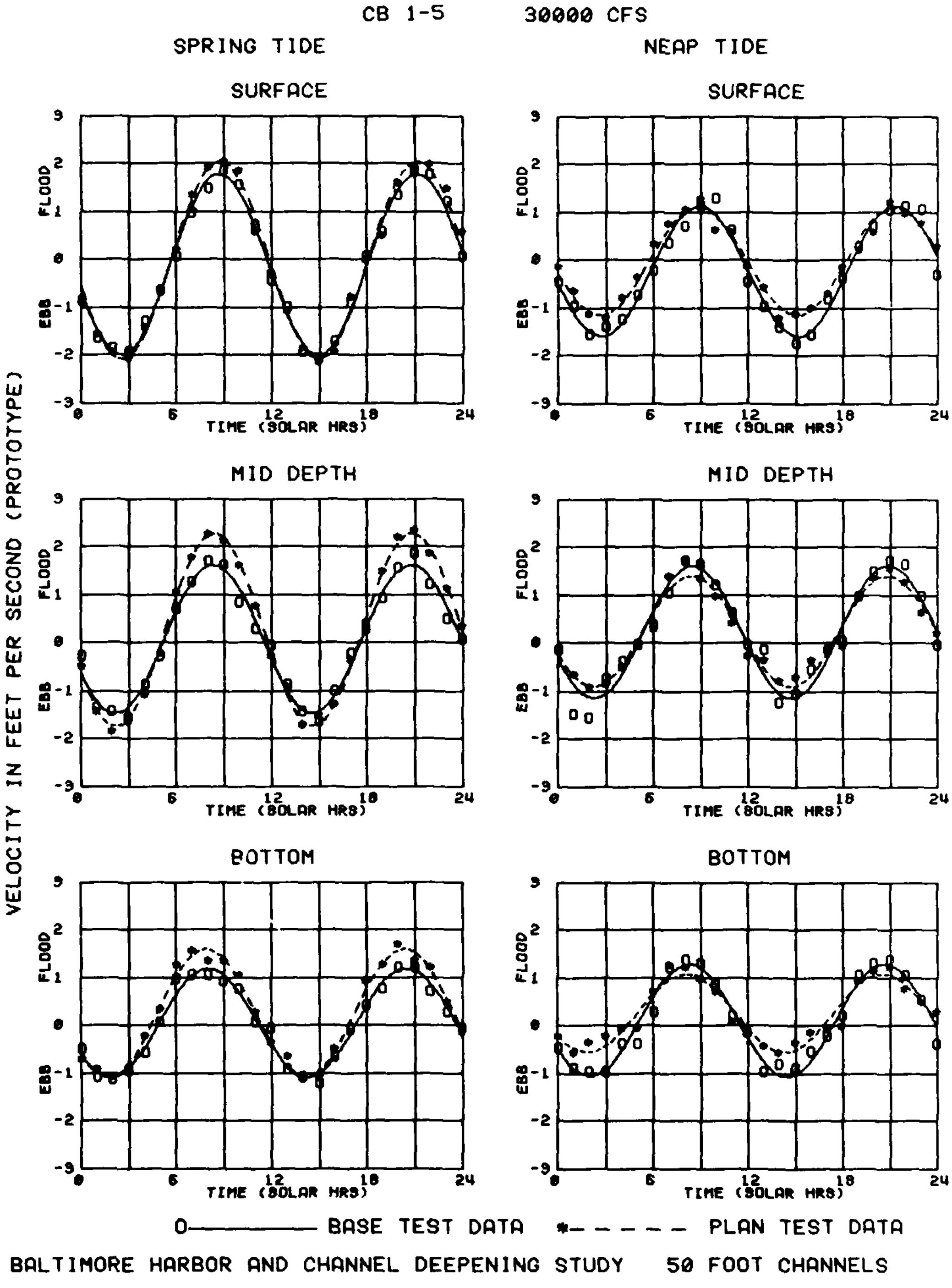


Plate 6. Sta CB-1-5 velocity during 30,000-cfs tests

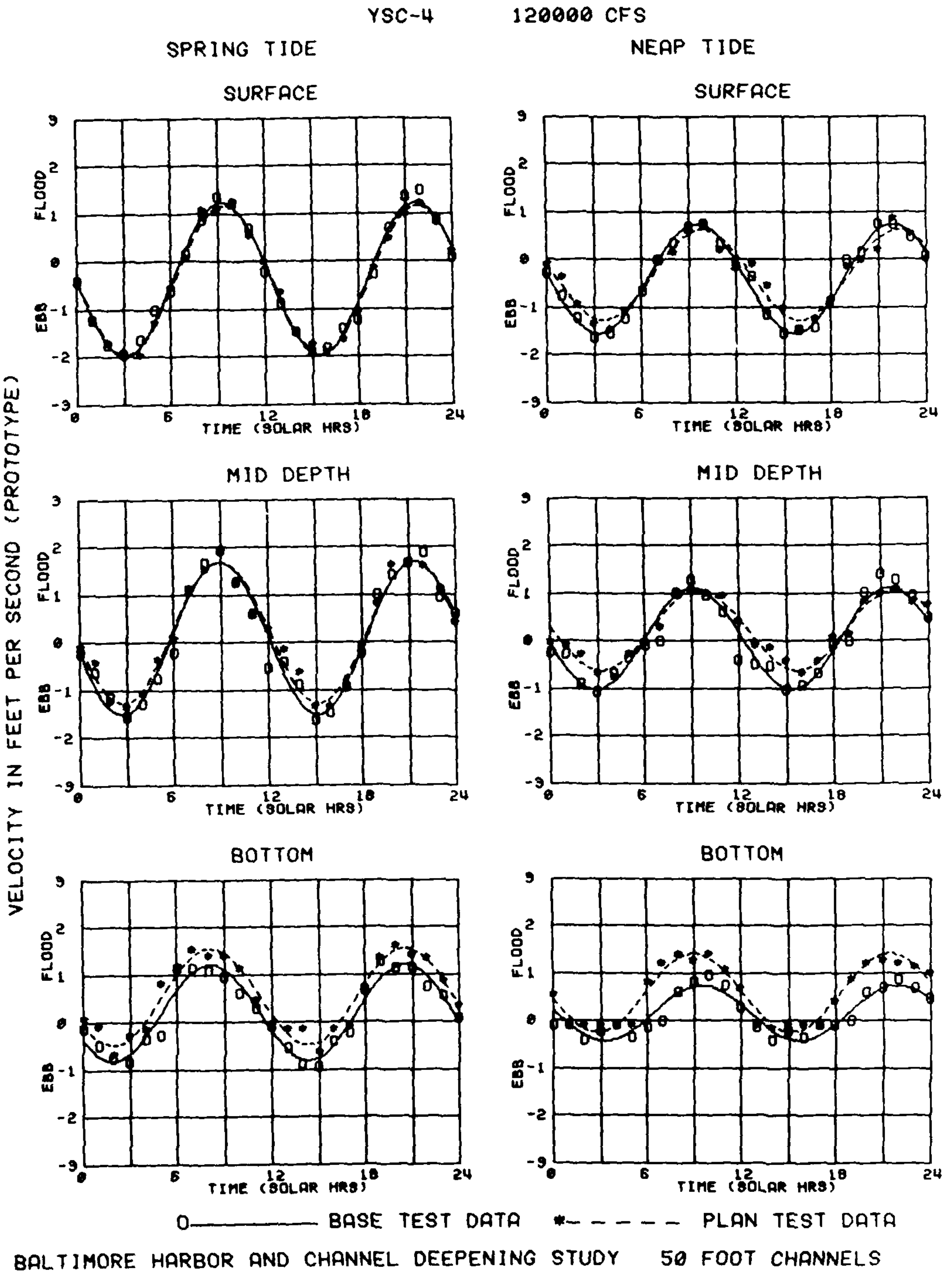


Plate 7. Sta YSC-4 velocity during 120,000-cfs tests

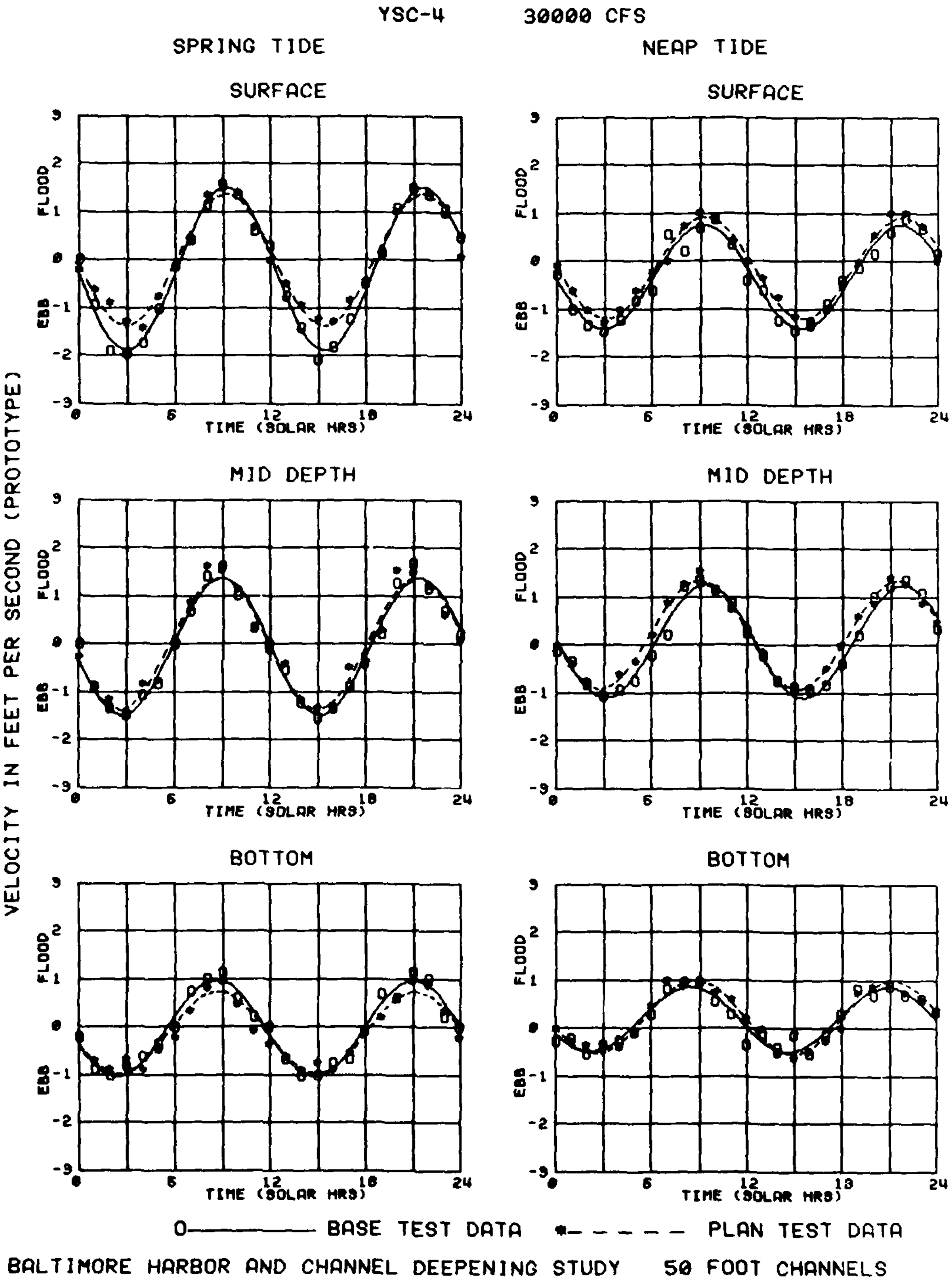


Plate 8. Sta YSC-4 velocity during 30,000-cfs tests

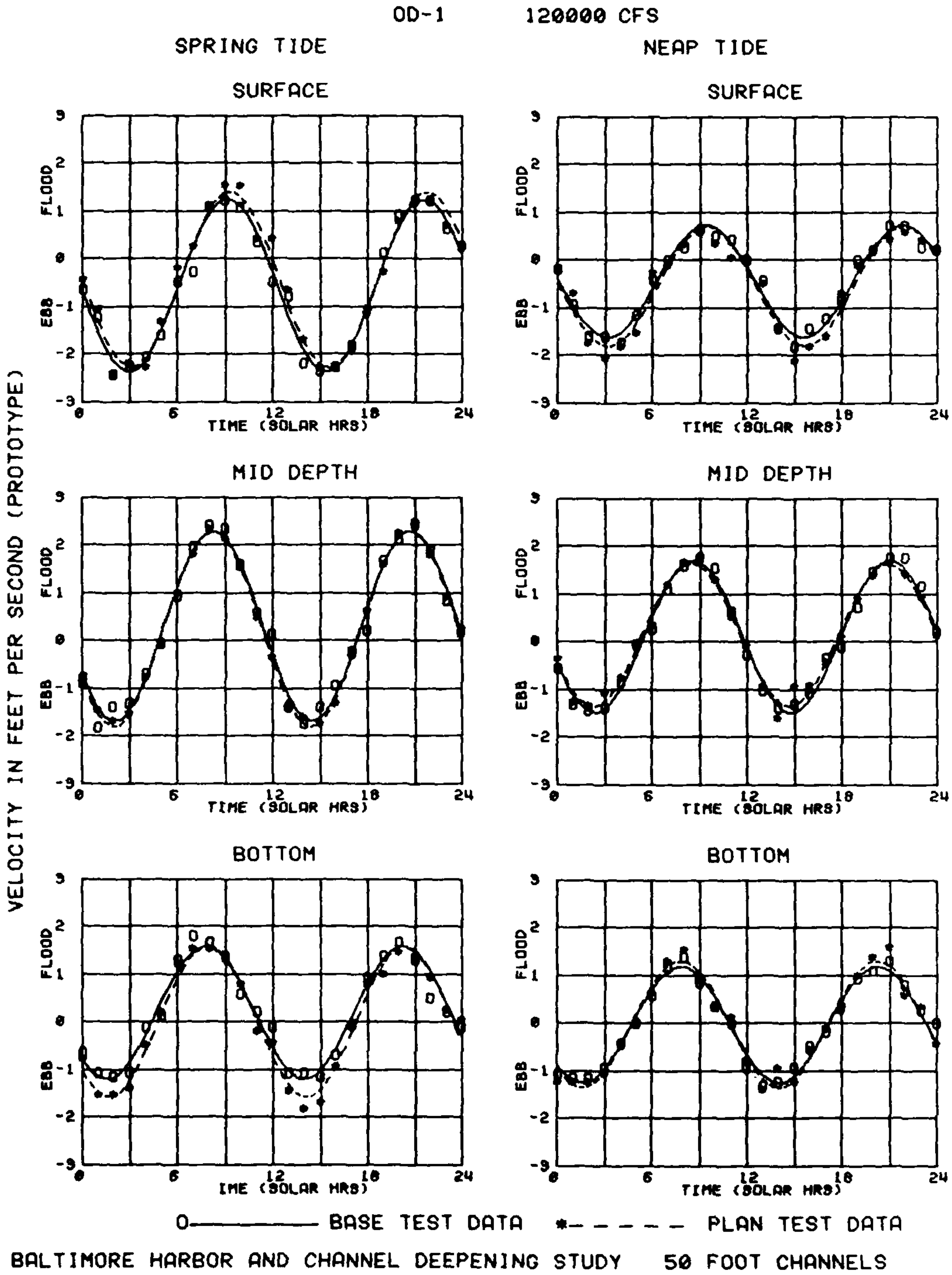


Plate 9. Sta OD-1 velocity during 120,000-cfs tests

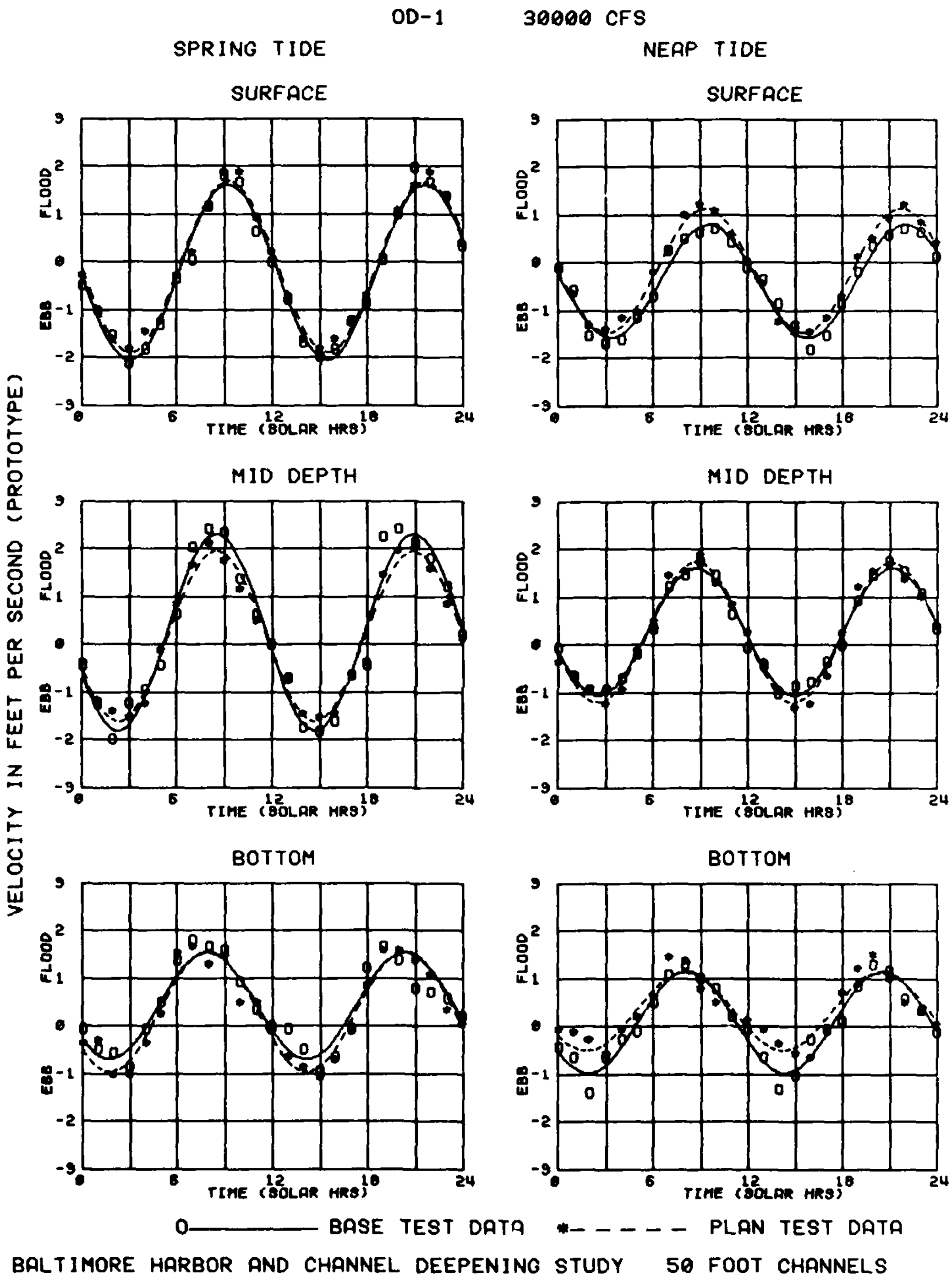


Plate 10. Sta OD-1 velocity during 30,000-cfs tests

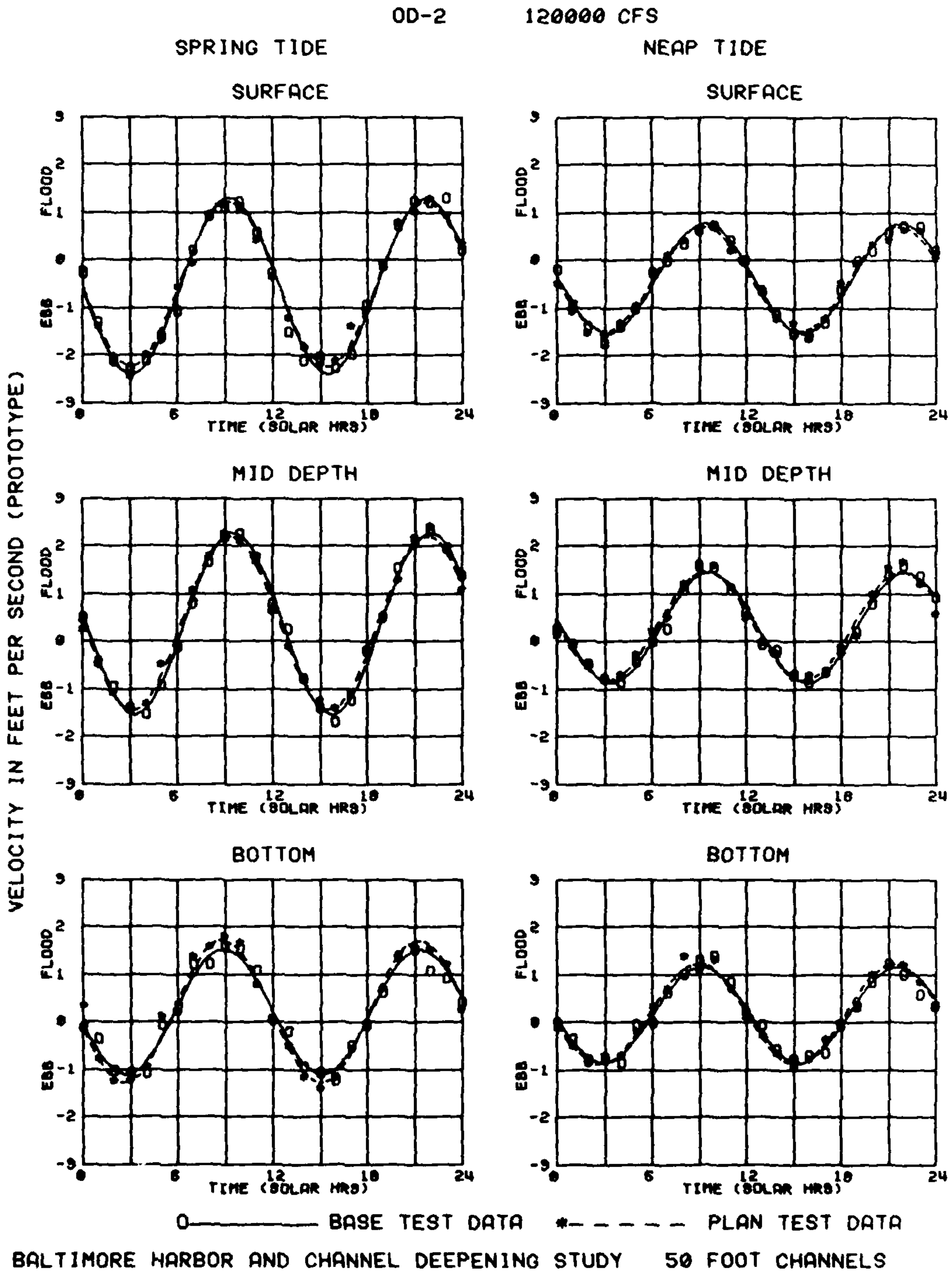


Plate 11. Sta OD-2 velocity during 120,000-cfs tests

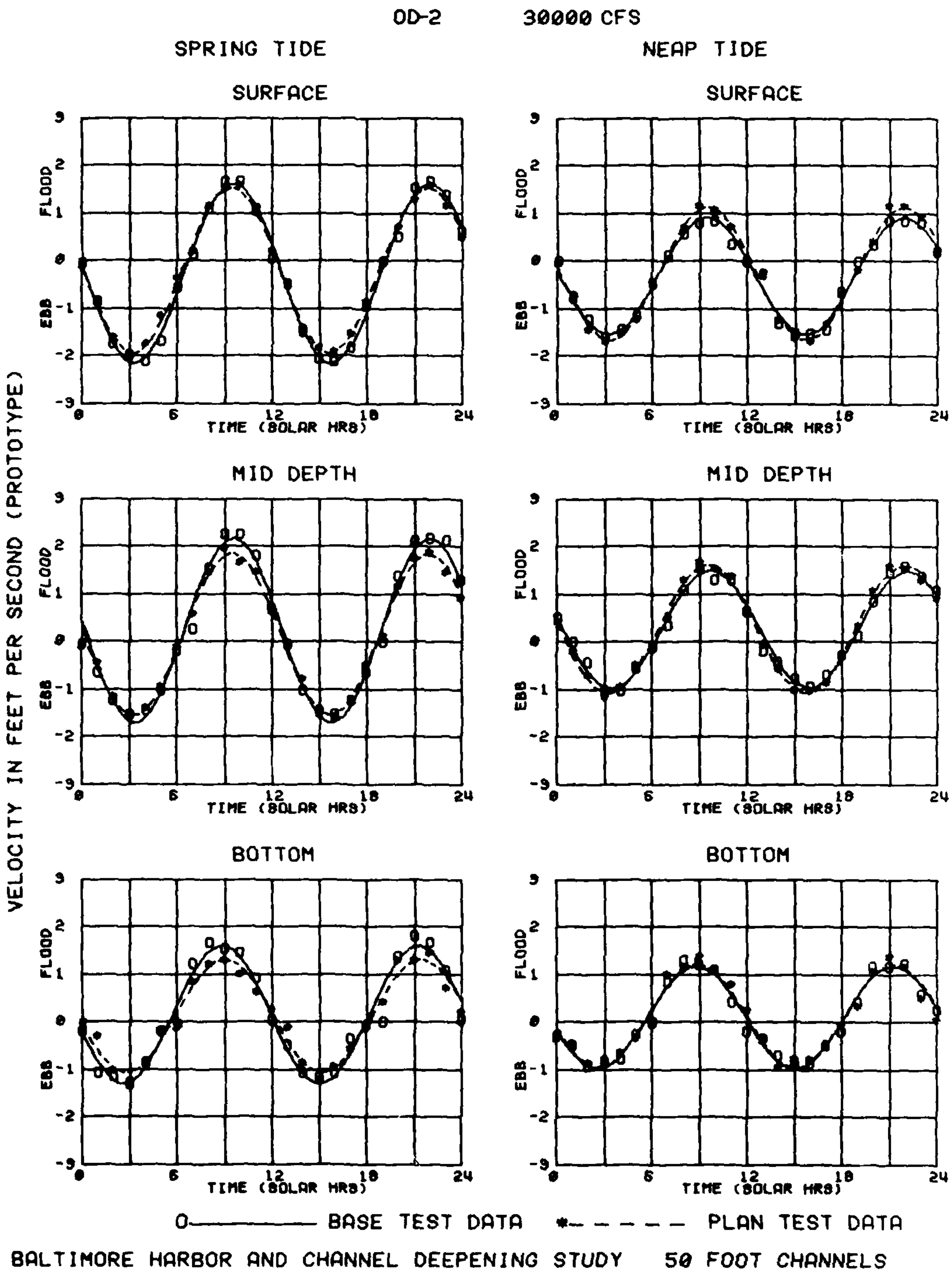


Plate 12. Sta OD-2 velocity during 30,000-cfs tests

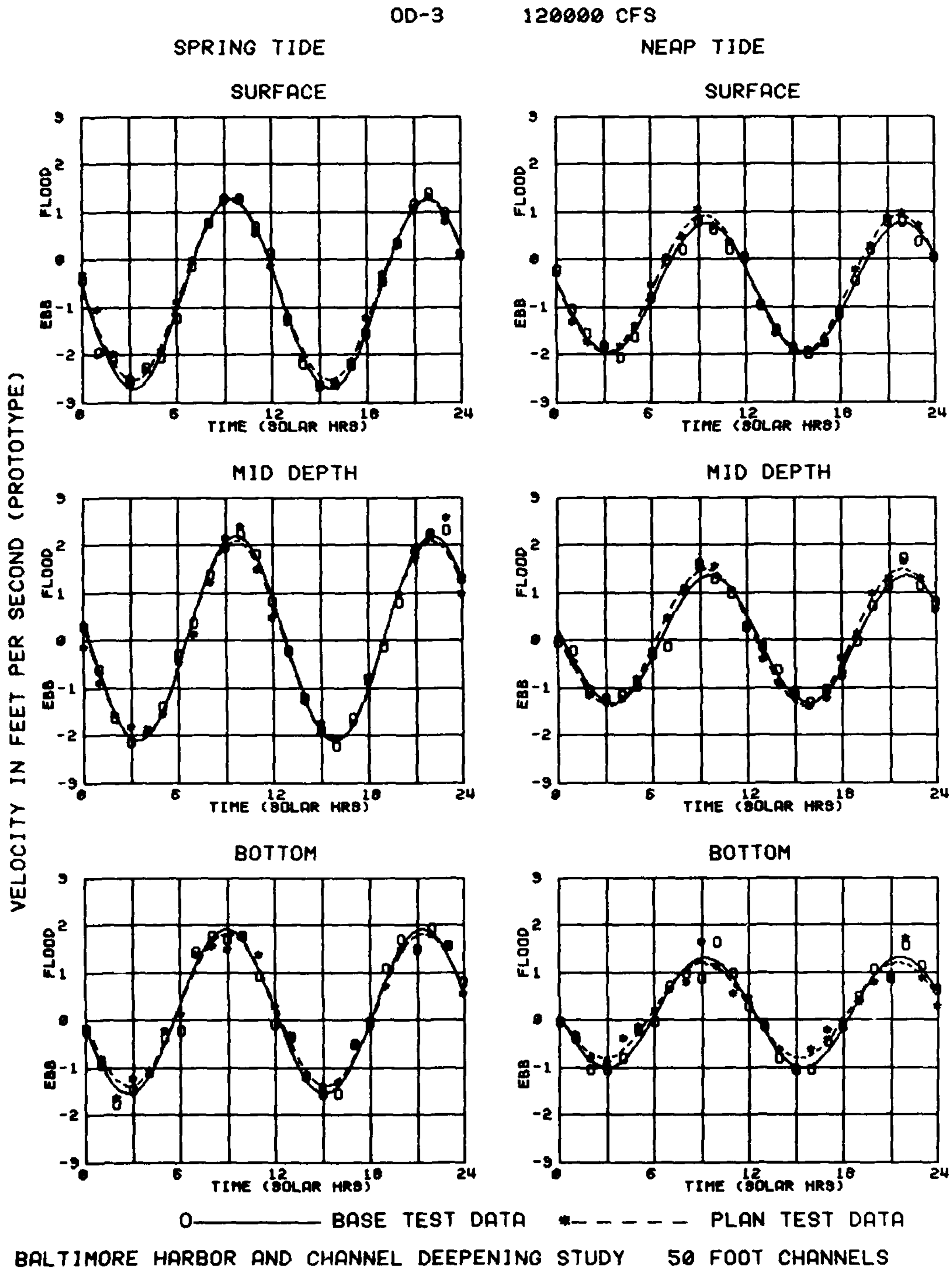


Plate 13. Sta OD-3 velocity during 120,000-cfs tests

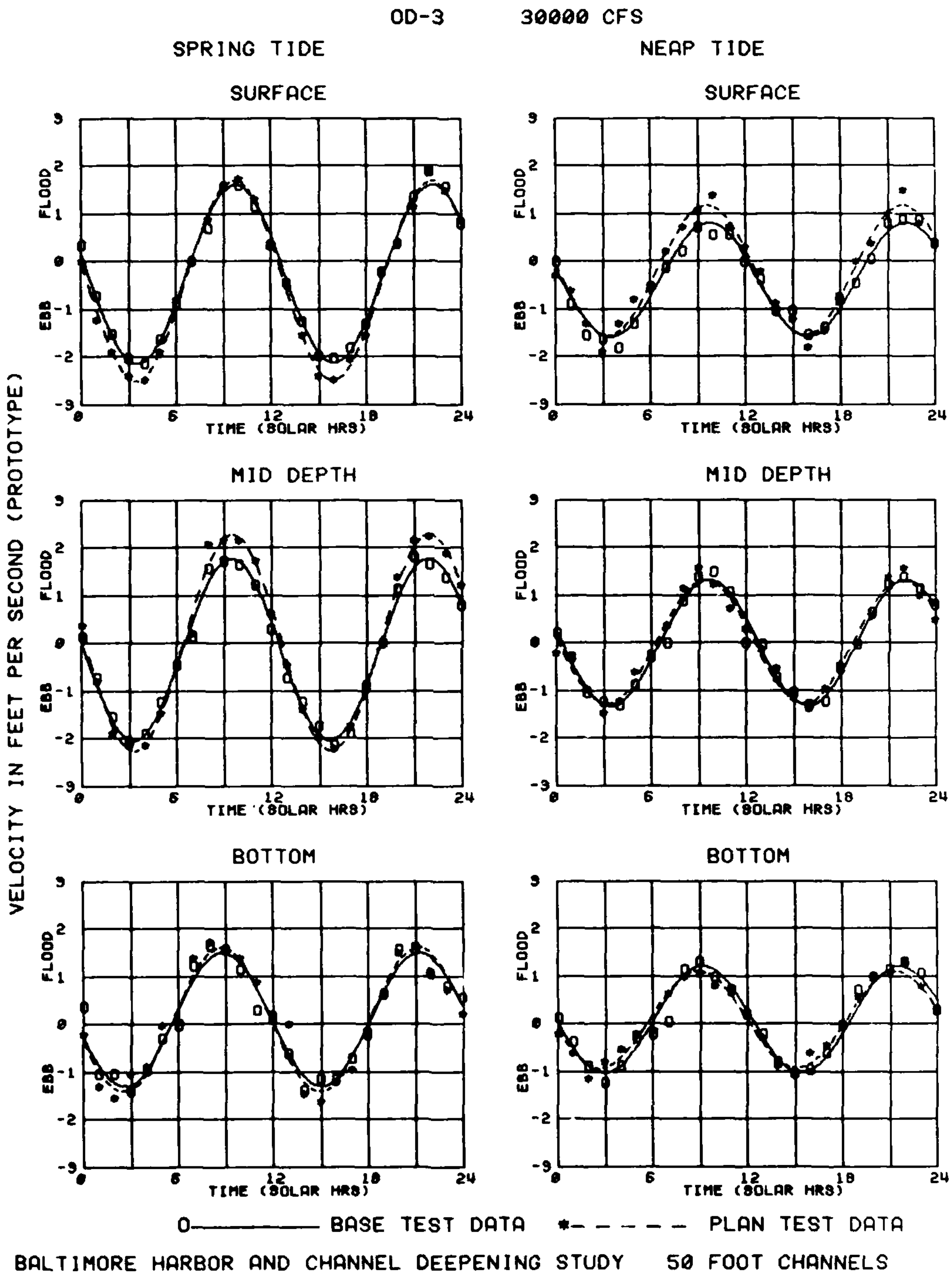


Plate 14. Sta OD-3 velocity during 30,000-cfs tests

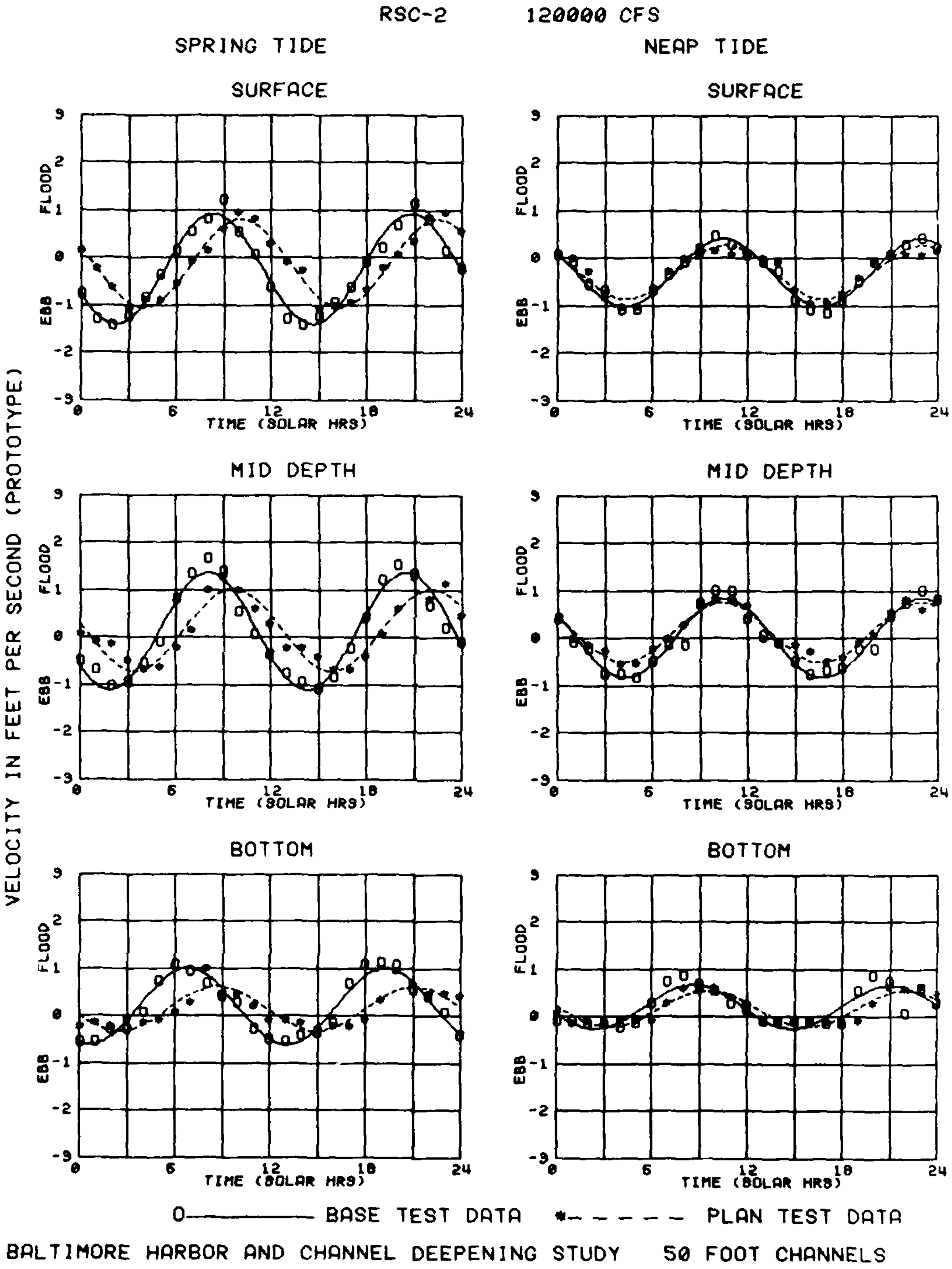


Plate 15. Sta RSC-2 velocity during 120,000-cfs tests

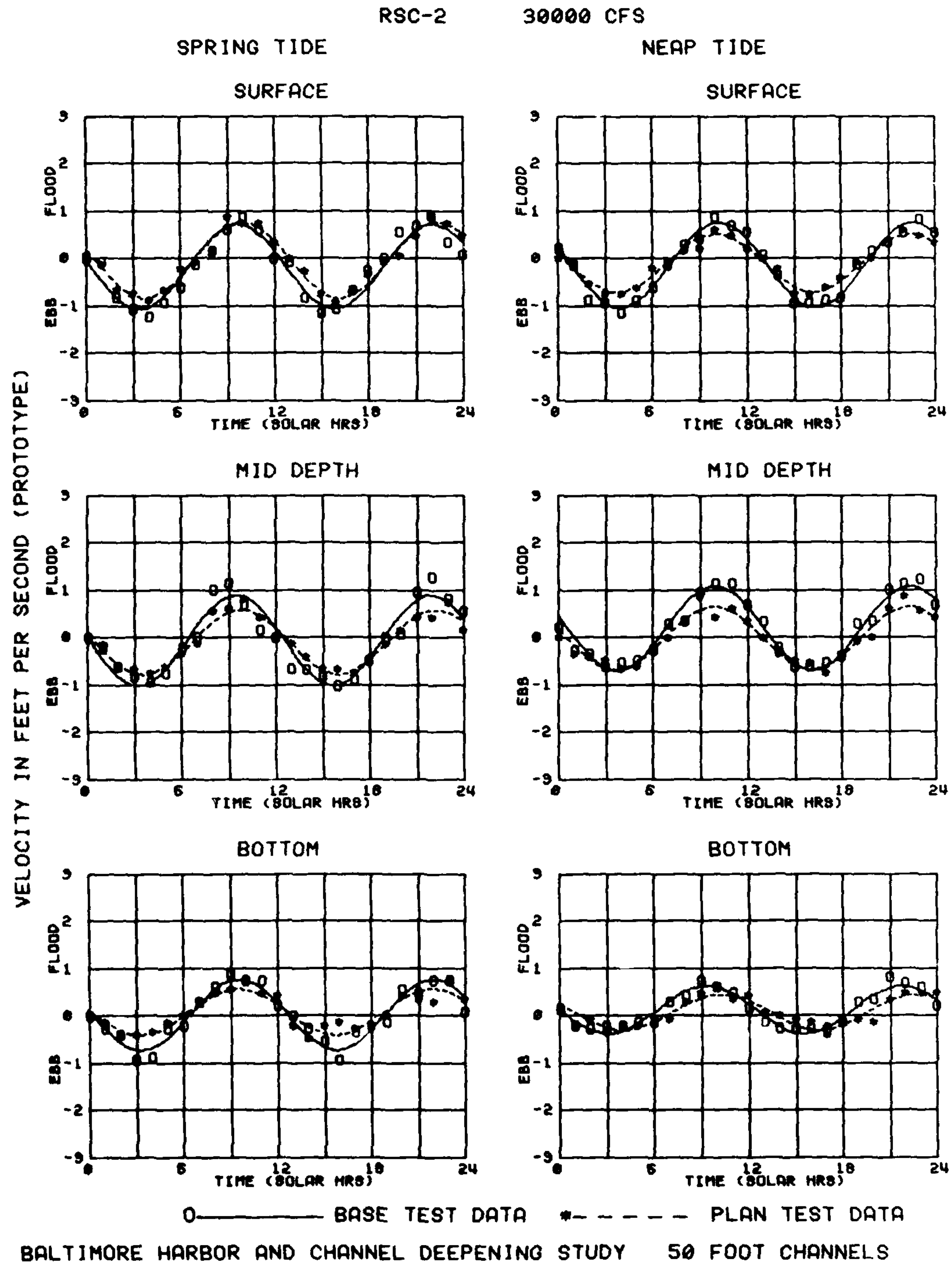


Plate 16. Sta RSC-2 velocity during 30,000-cfs tests

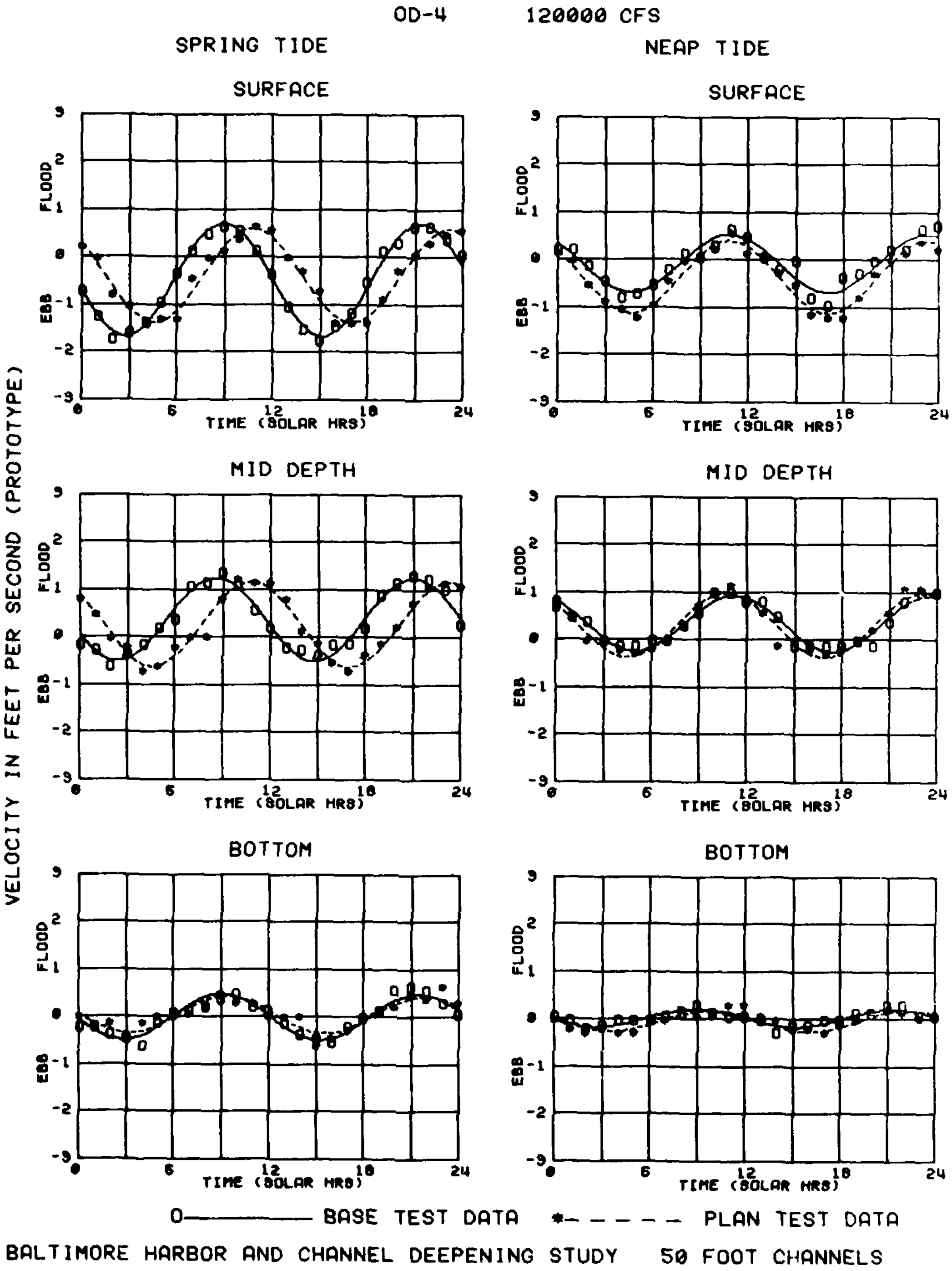


Plate 17. Sta OD-4 velocity during 120,000-cfs tests

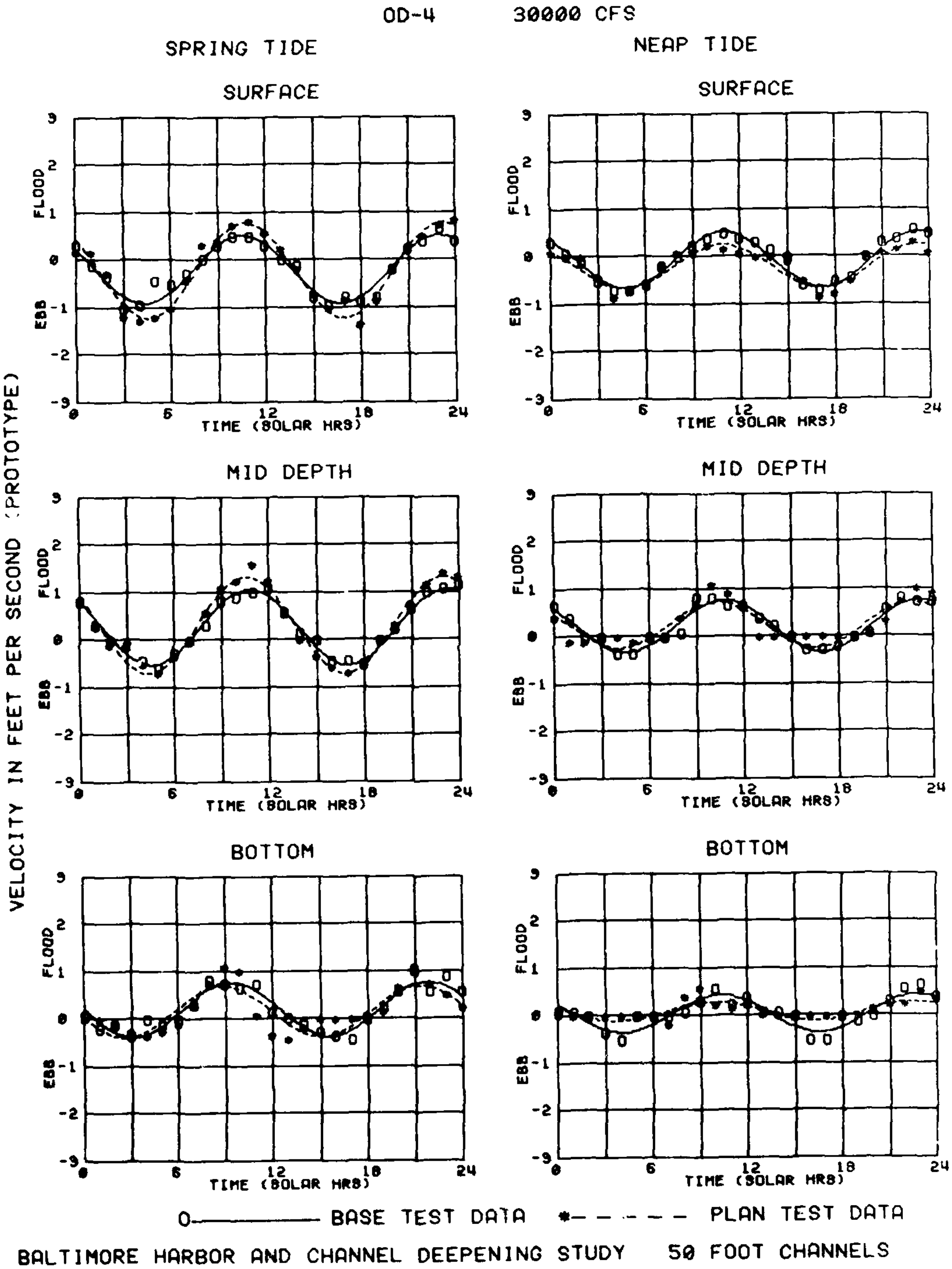


Plate 18. Sta OD-4 velocity during 30,000-cfs tests

AD-A114 283 ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG--ETC F/G 8/3
BALTIMORE HARBOR AND CHANNELS DEEPENING STUDY; CHESAPEAKE BAY H--ETC(U)
FEB 82 M A GRANAT, L F GULBRANDSEN
UNCLASSIFIED WES-TR-HL-82-5 NL

2 OF 3
AD A
114283

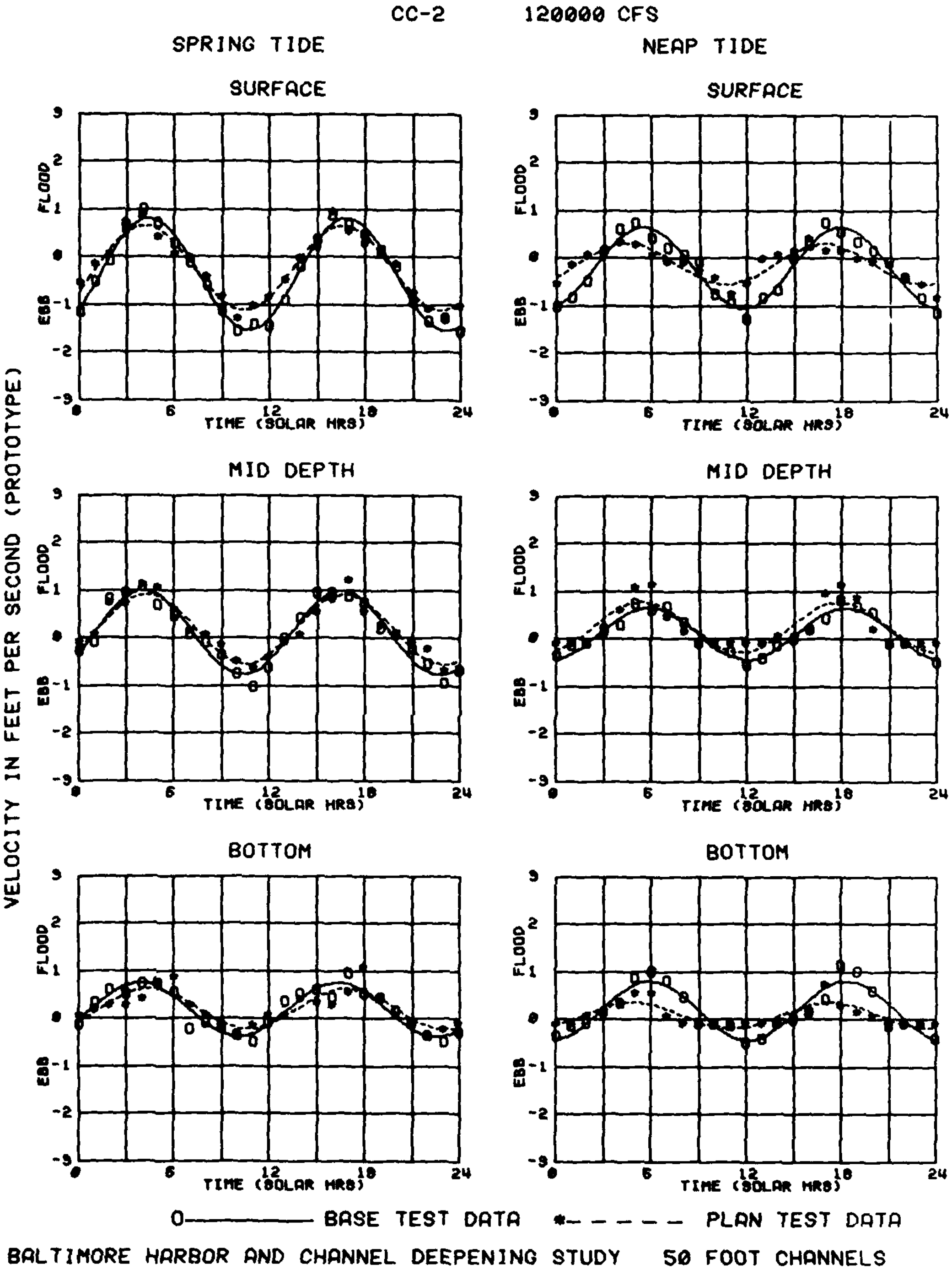


Plate 19. Sta CC-2 velocity during 120,000-cfs tests

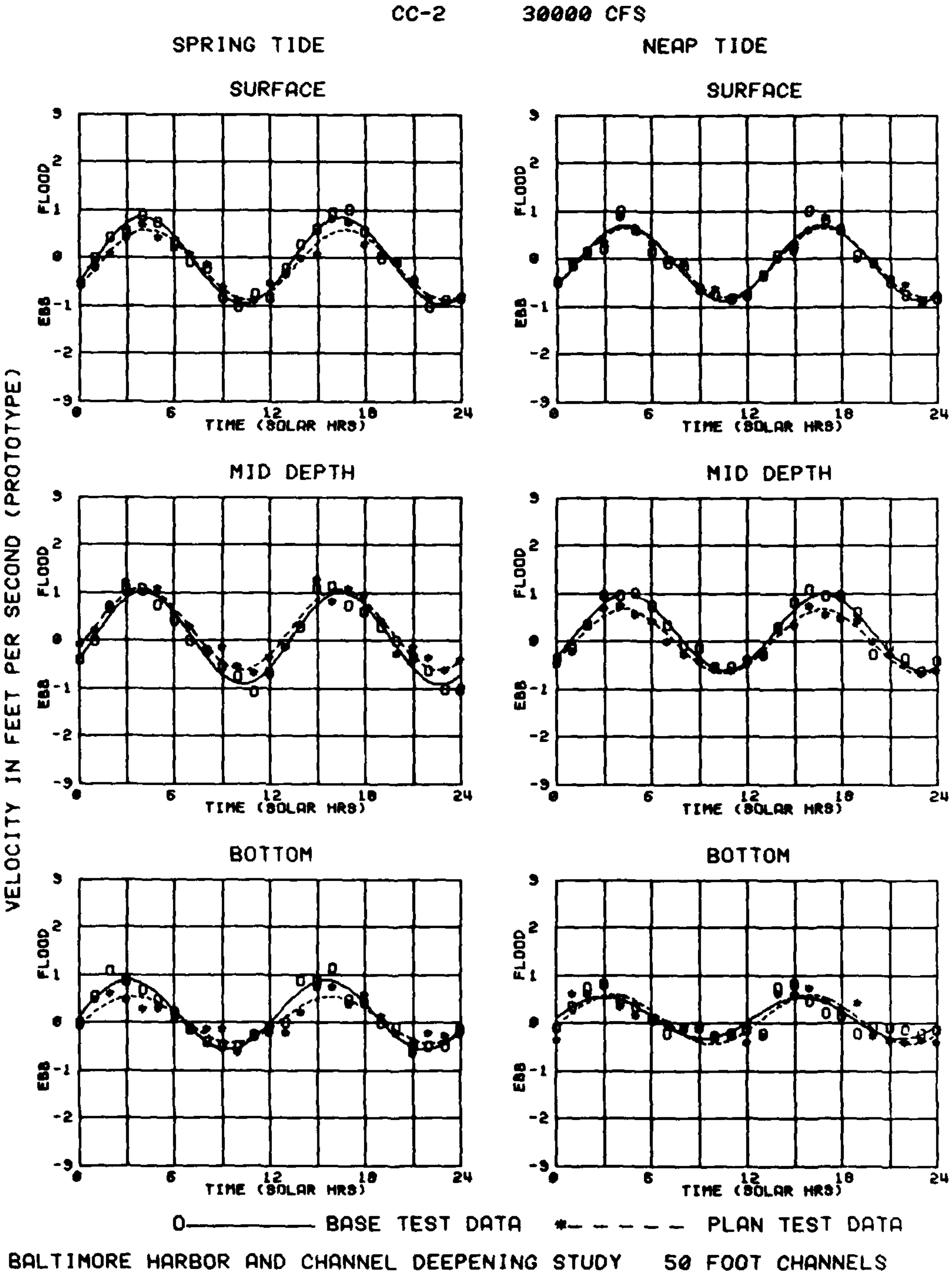


Plate 20. Sta CC-2 velocity during 30,000-cfs tests

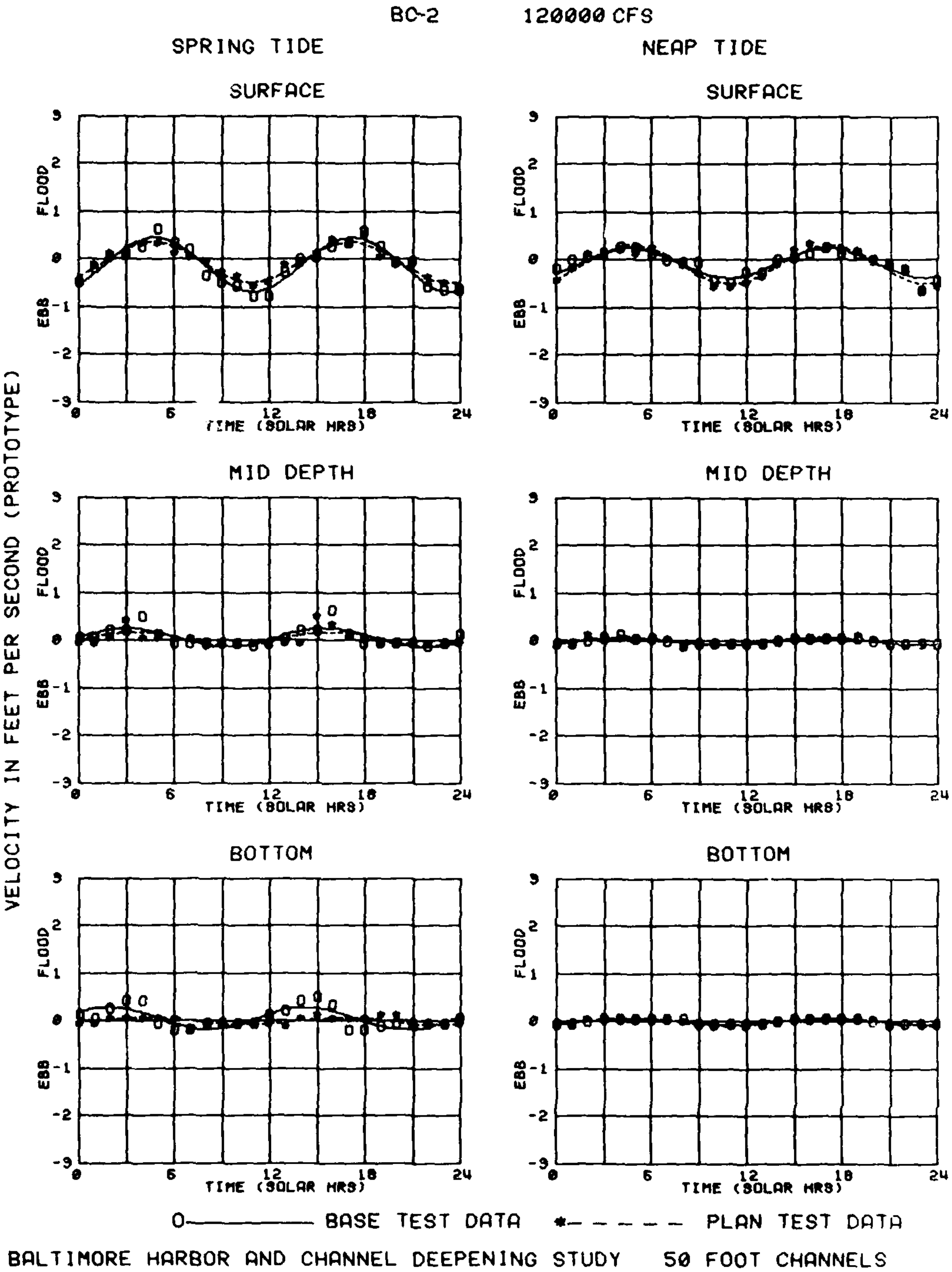


Plate 21. Sta BC-2 velocity during 120,000-cfs tests

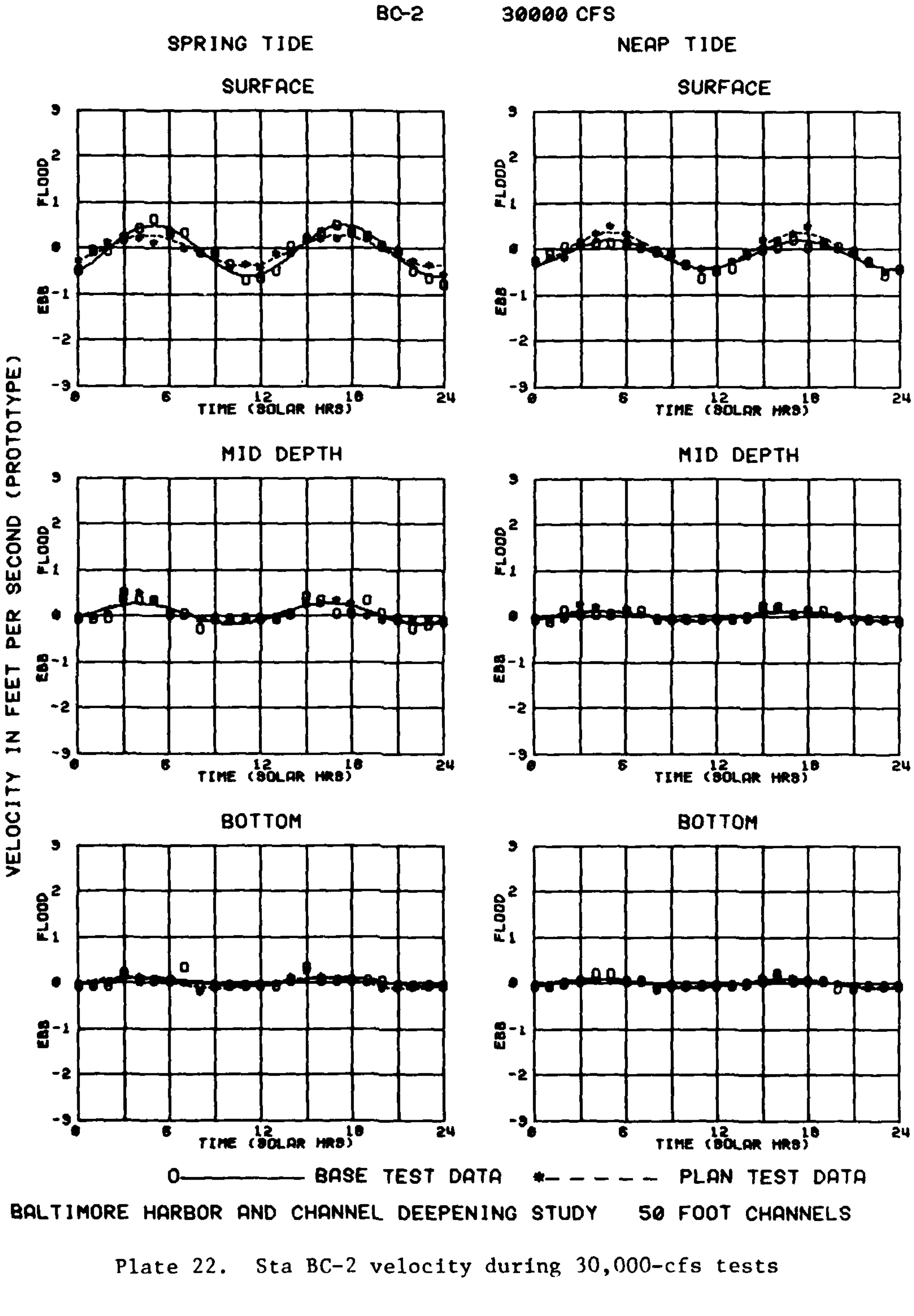


Plate 22. Sta BC-2 velocity during 30,000-cfs tests

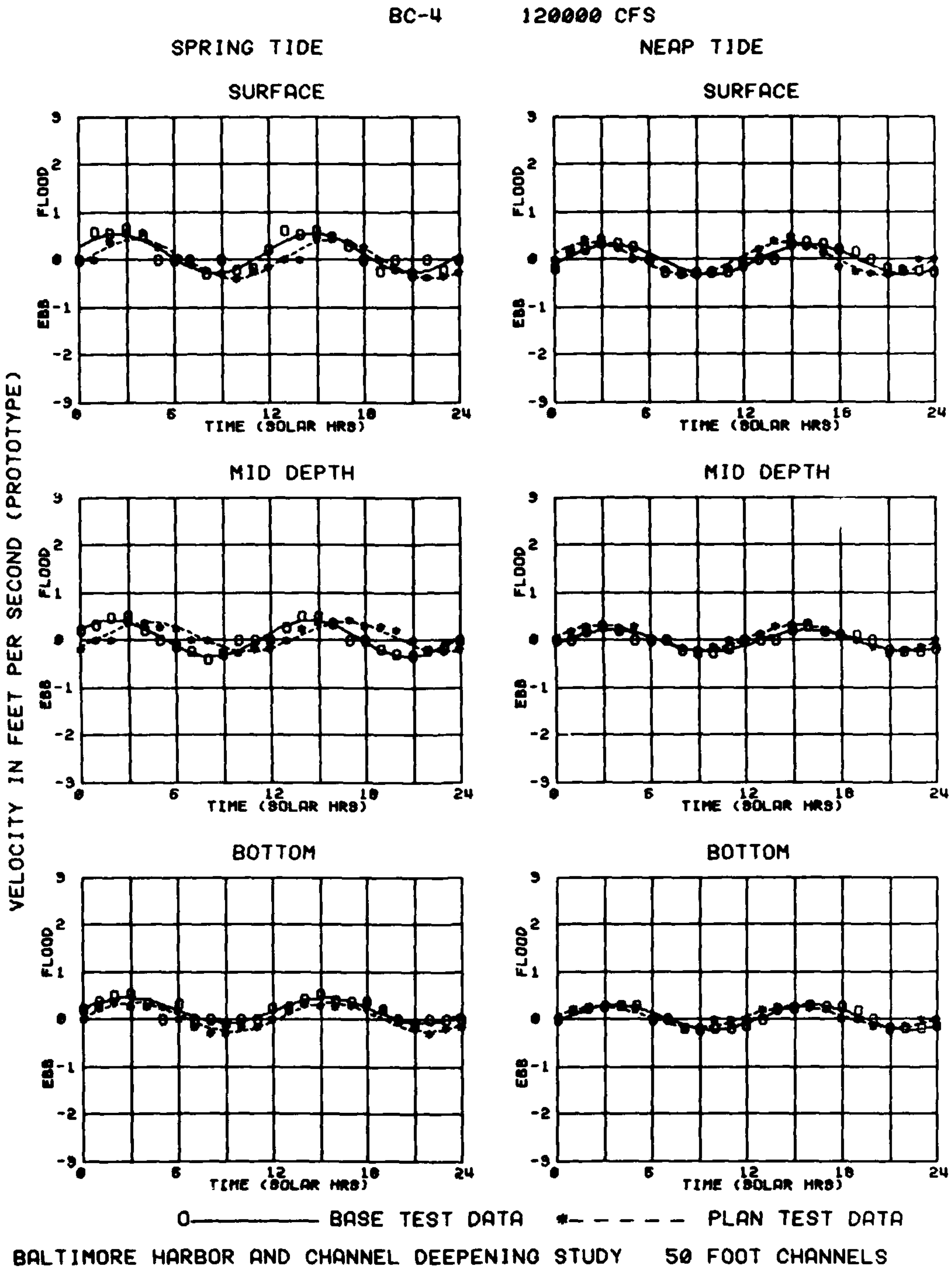


Plate 23. Sta BC-4 velocity during 120,000-cfs tests

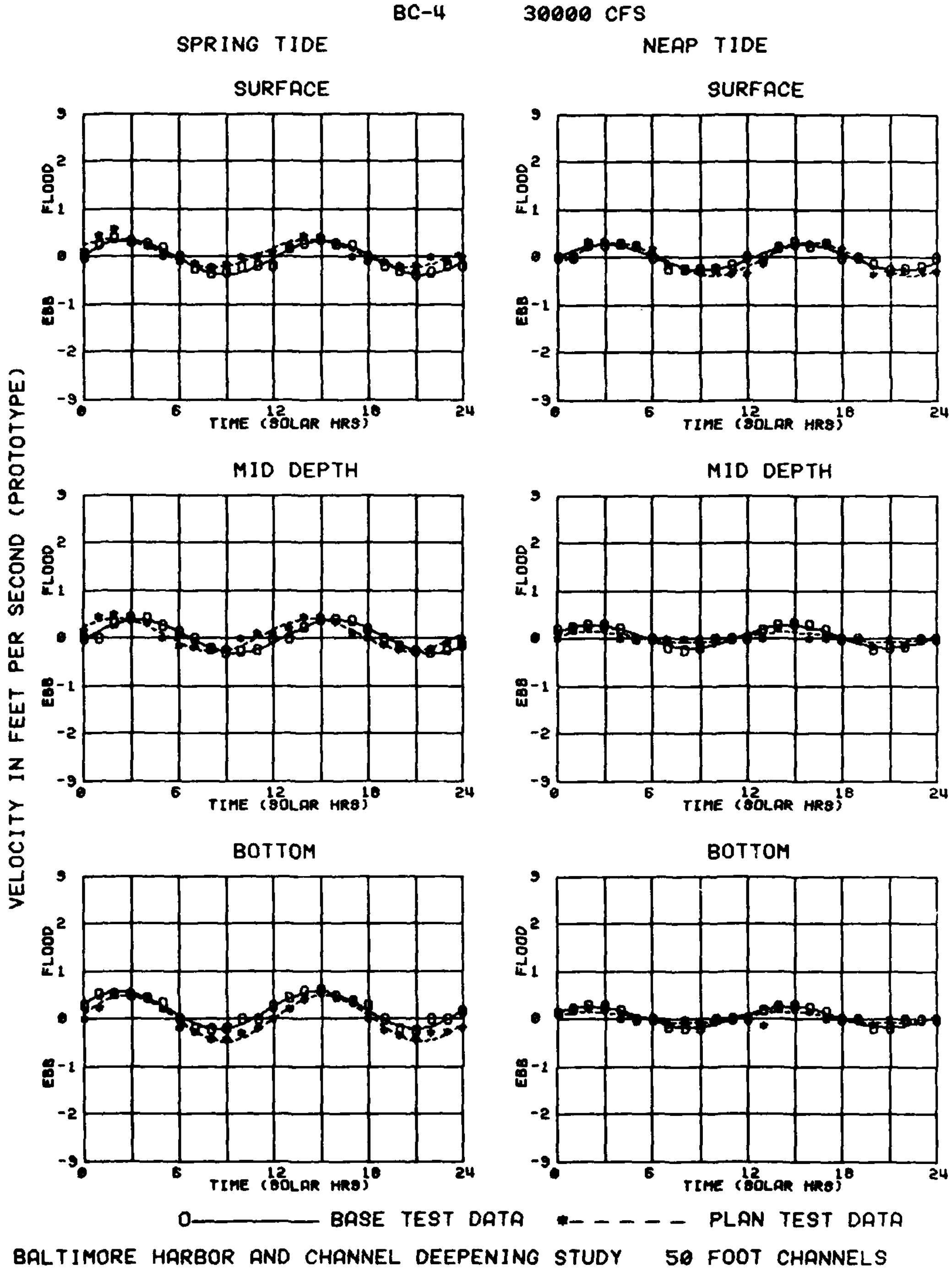


Plate 24. Sta BC-4 velocity during 30,000-cfs tests

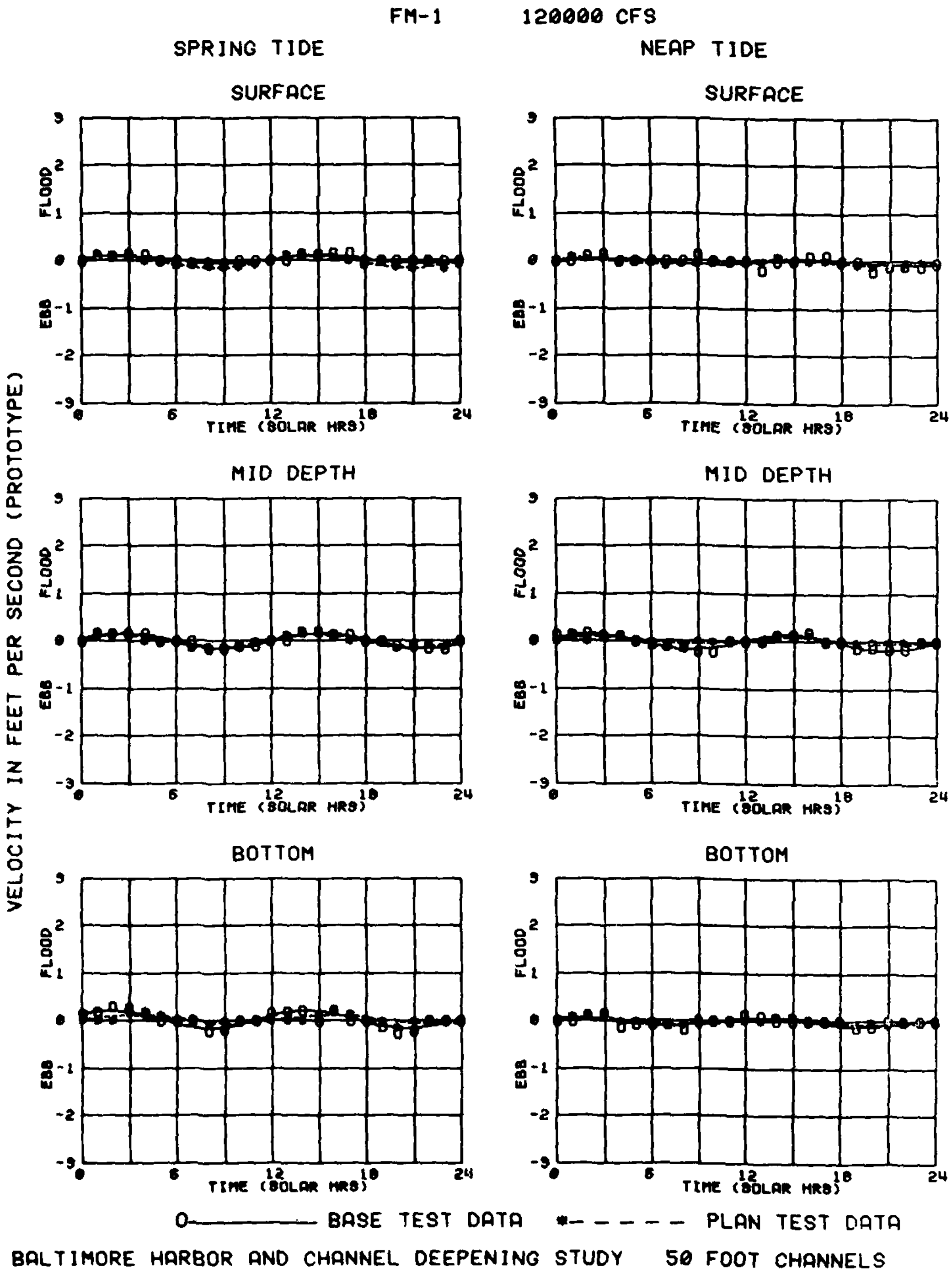


Plate 25. Sta FM-1 velocity during 120,000-cfs tests

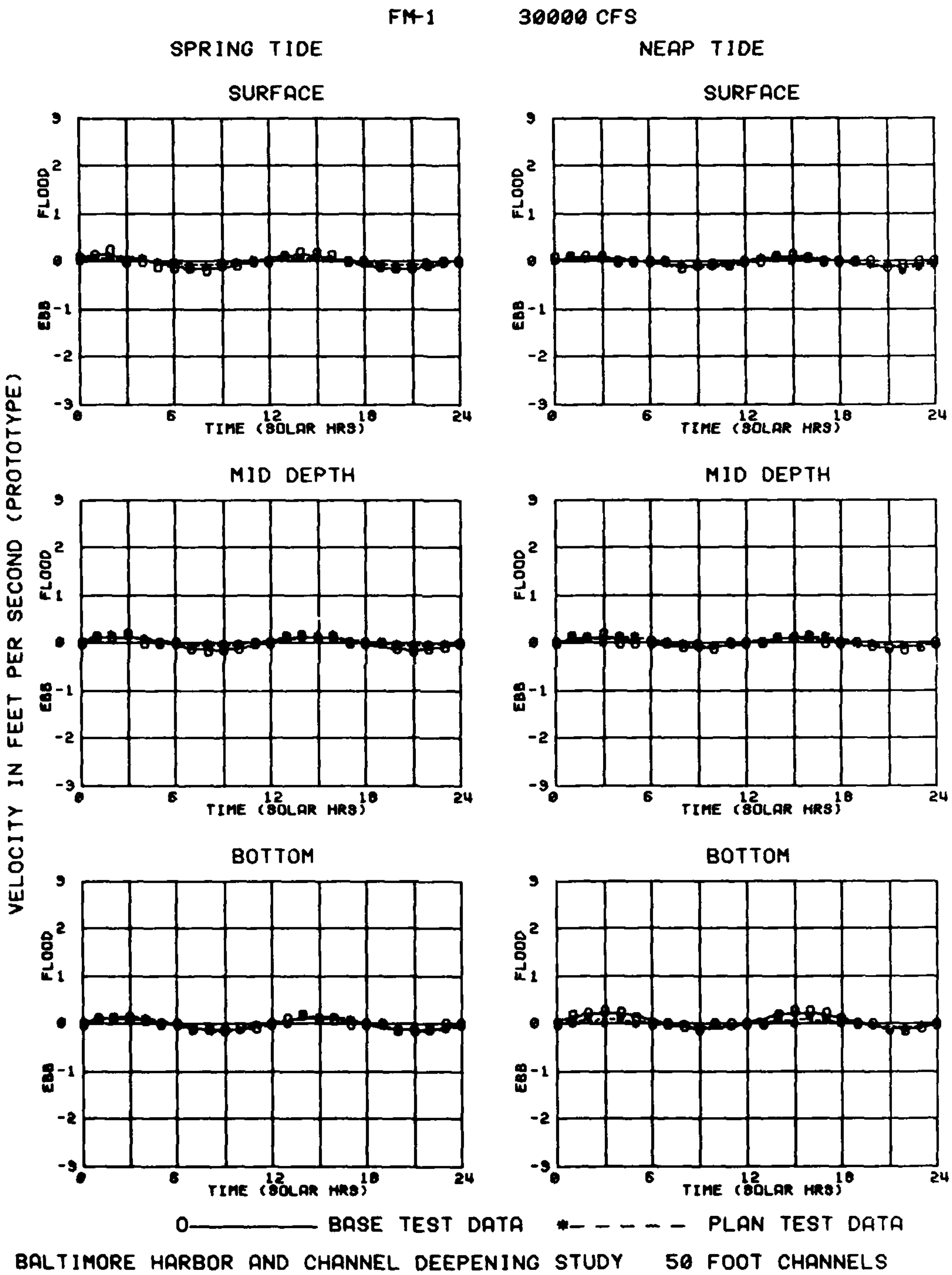
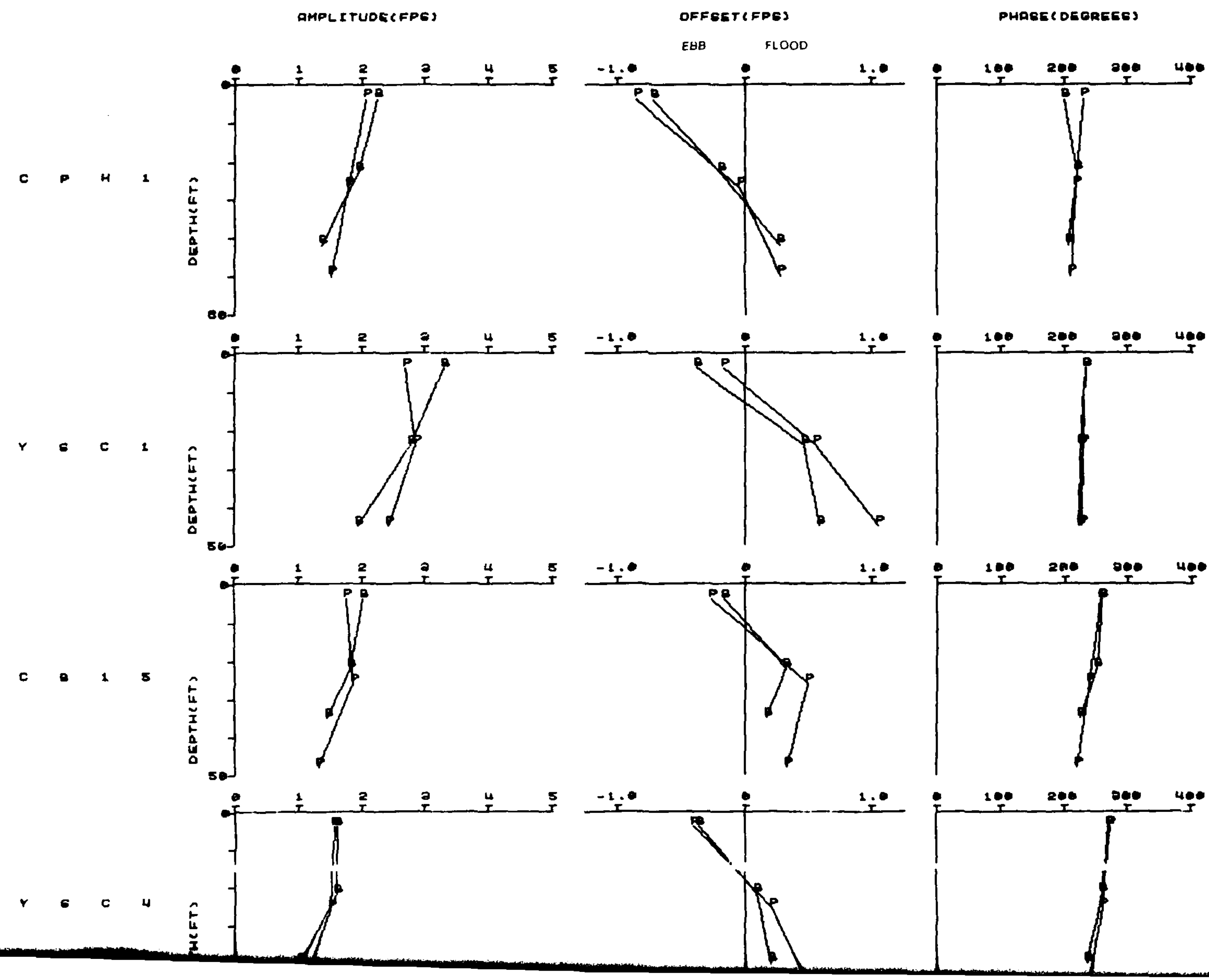


Plate 26. Sta FM-1 velocity during 30,000-cfs tests

PLAN AND BASE PHASE, OFFSET, AMPLITUDE

SPRING 120000



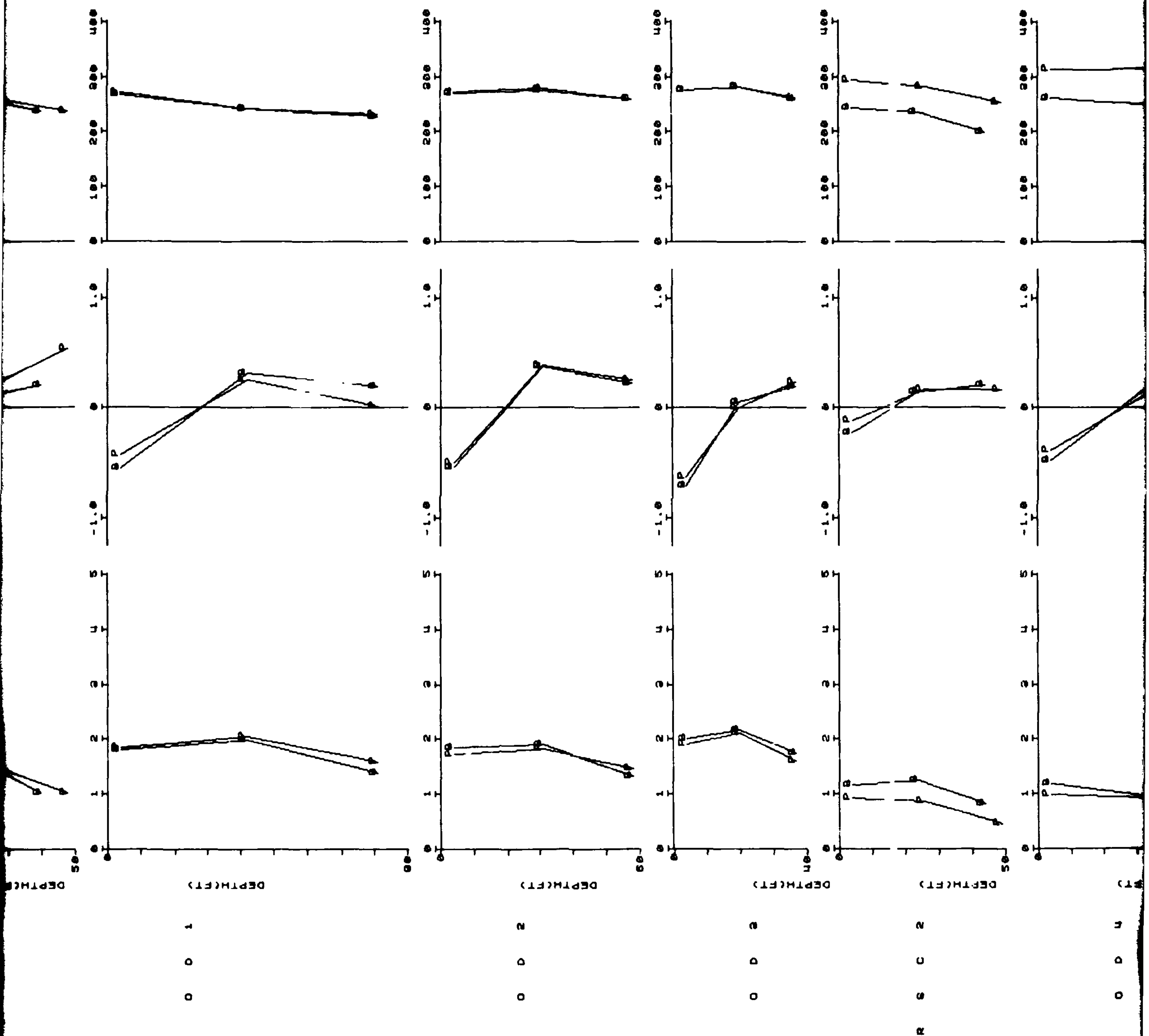
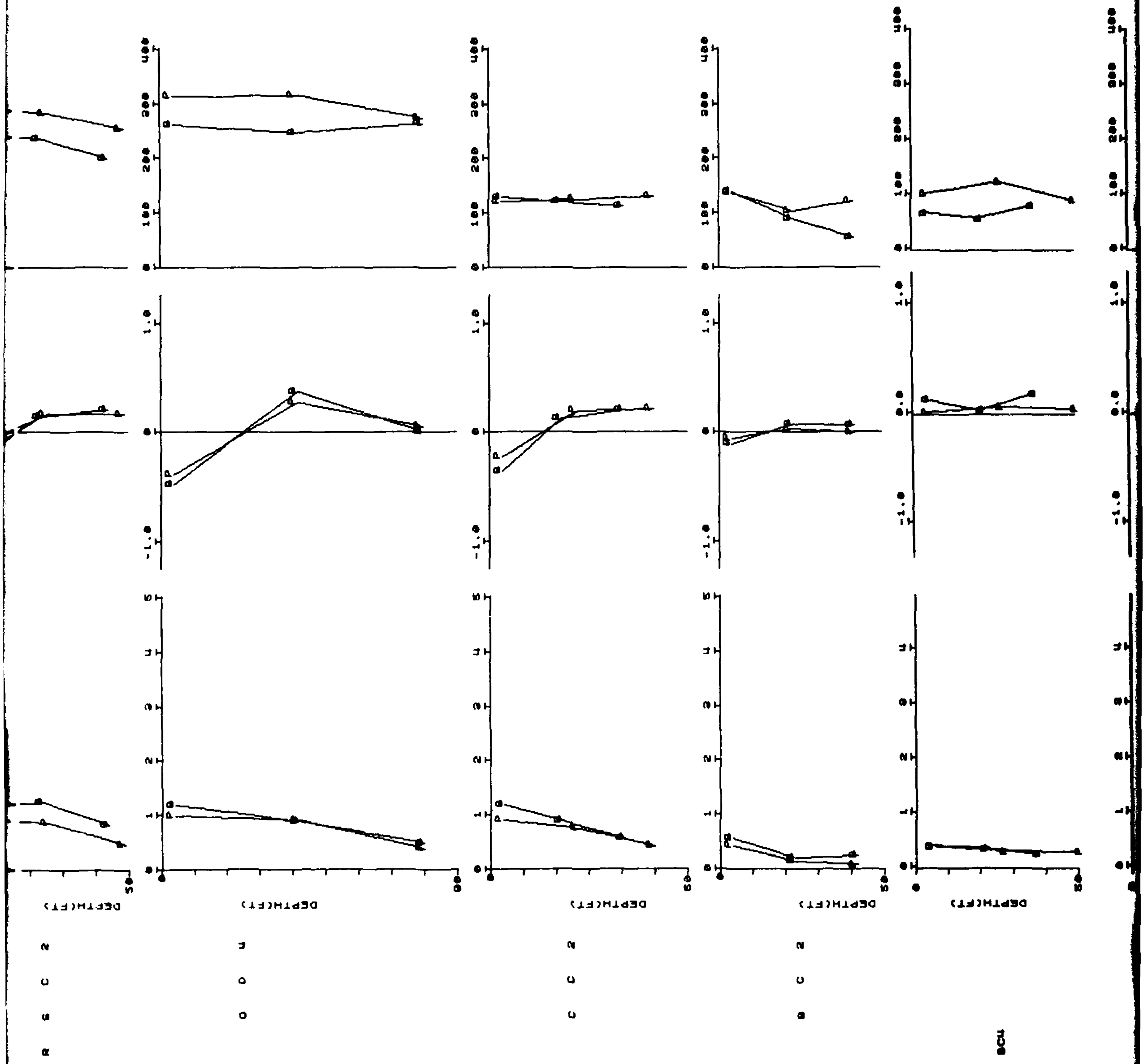
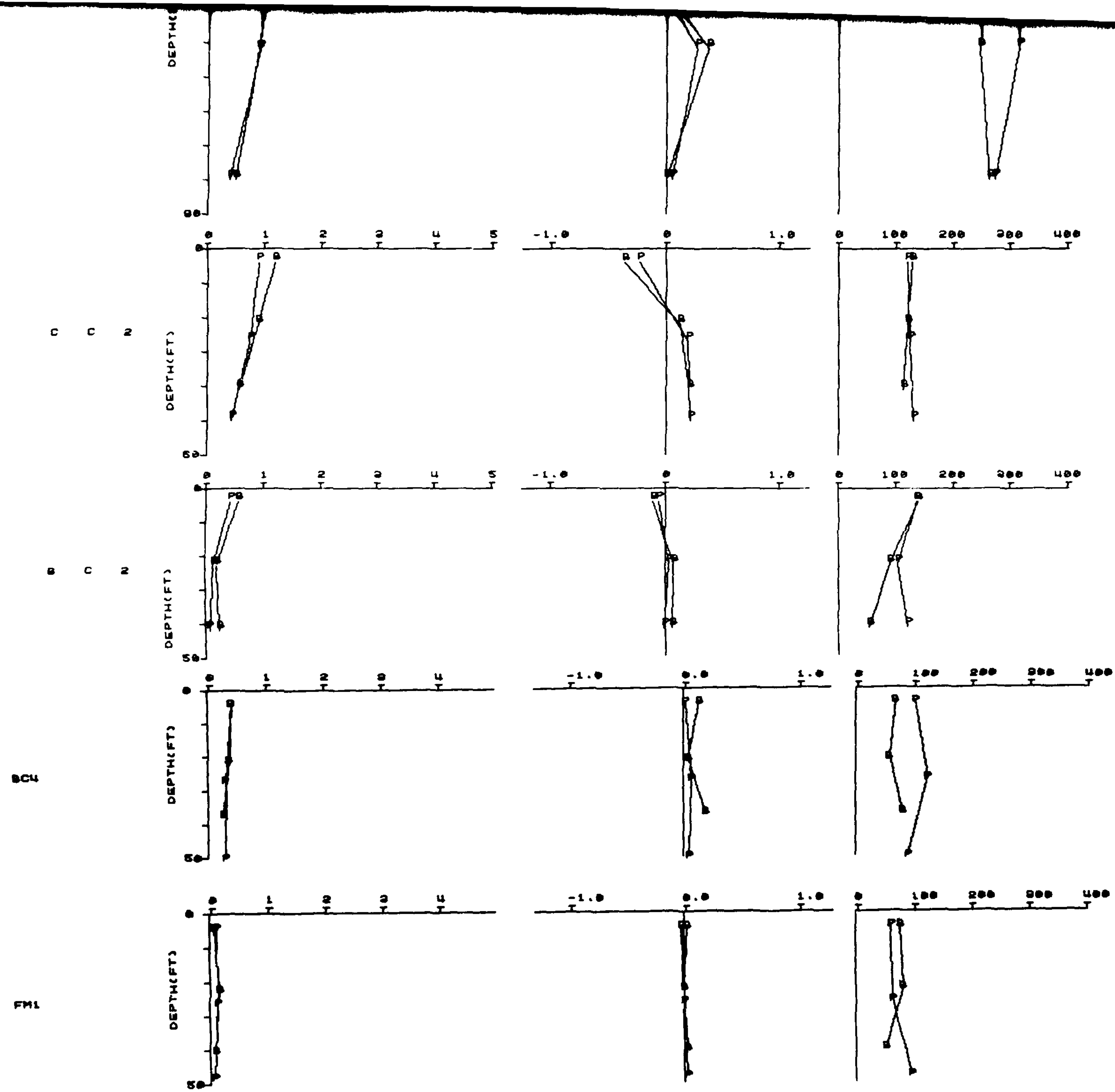


Plate 27. Vertical phase, amplitude, and offset during 120,000-cfs spring tide test



cfs spring tide test

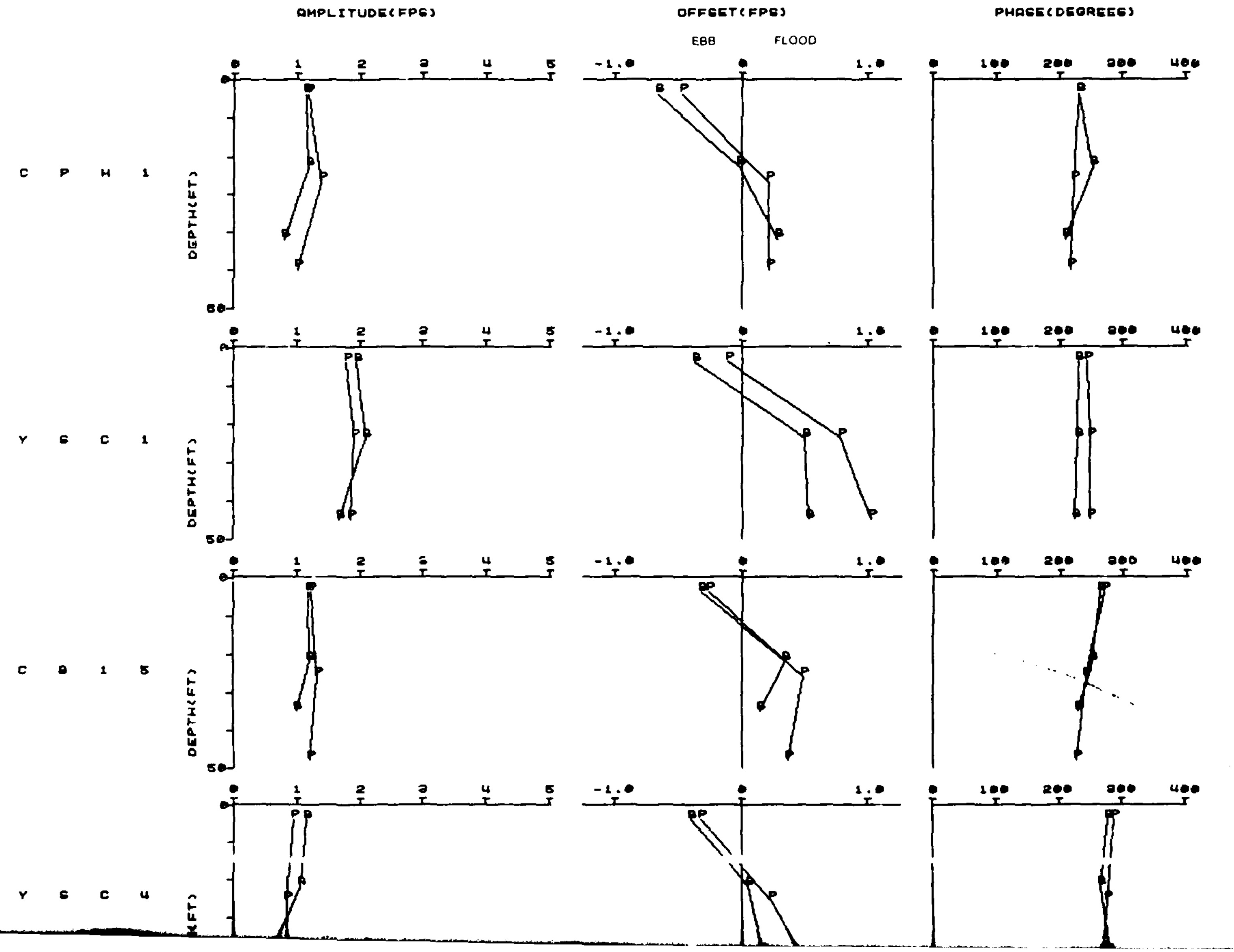

C C 2
B C 2
BC4
FM1
DEPTH(FT)

PLAN AND BASE PHASE. OFFSET. AMPLITUDE

NEAP 120000

KEY

P = PLAN
B = BASE



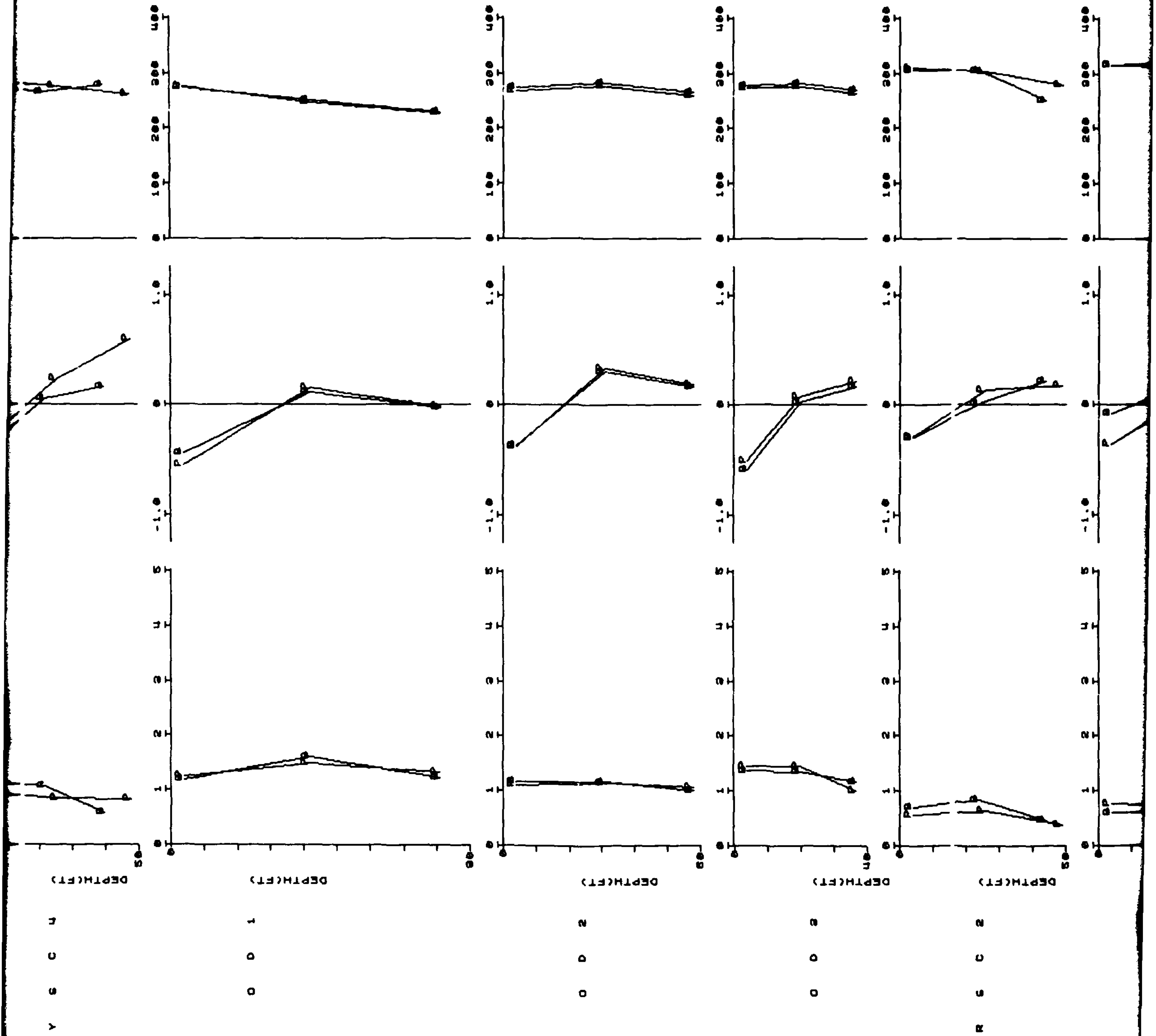
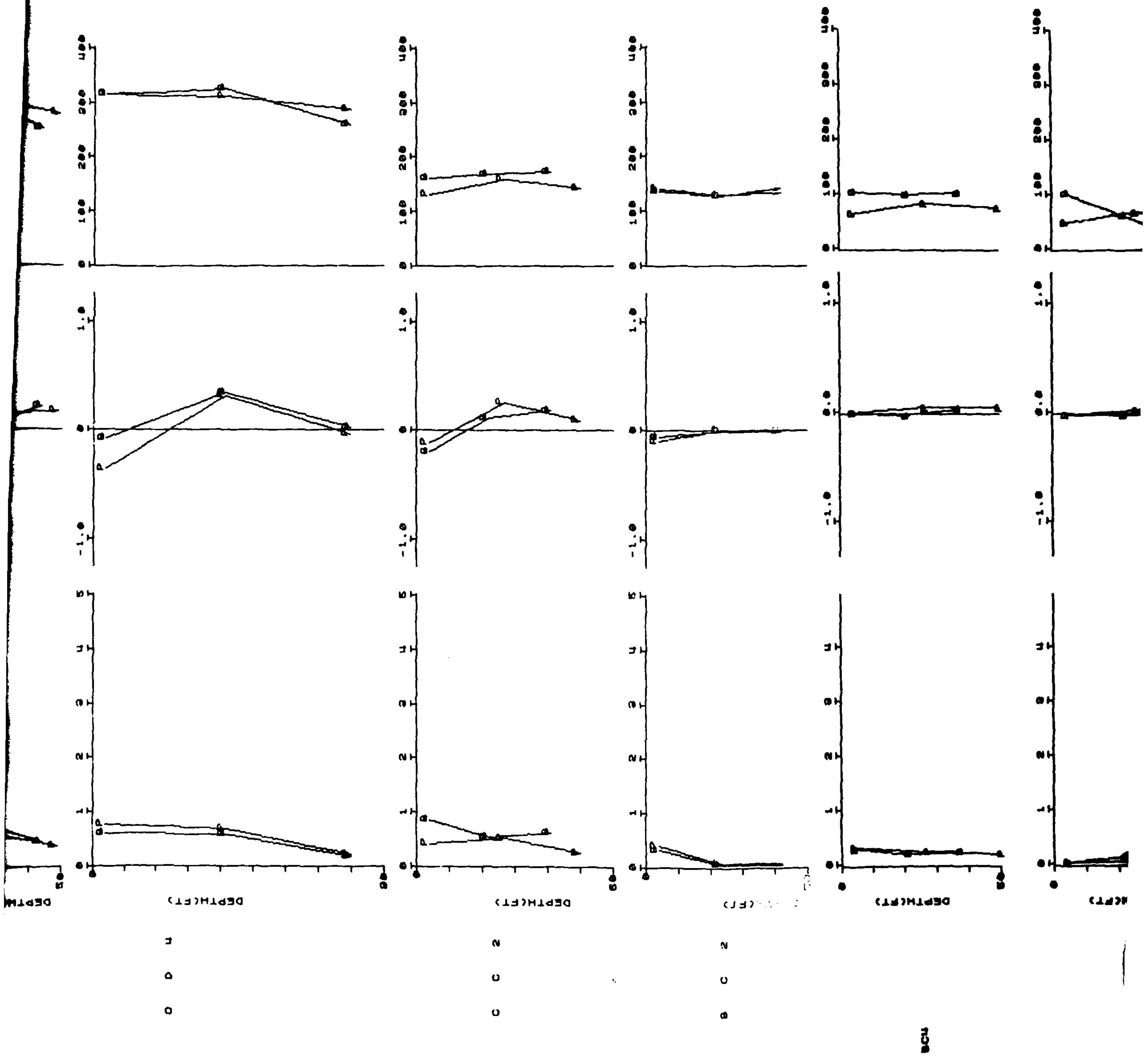
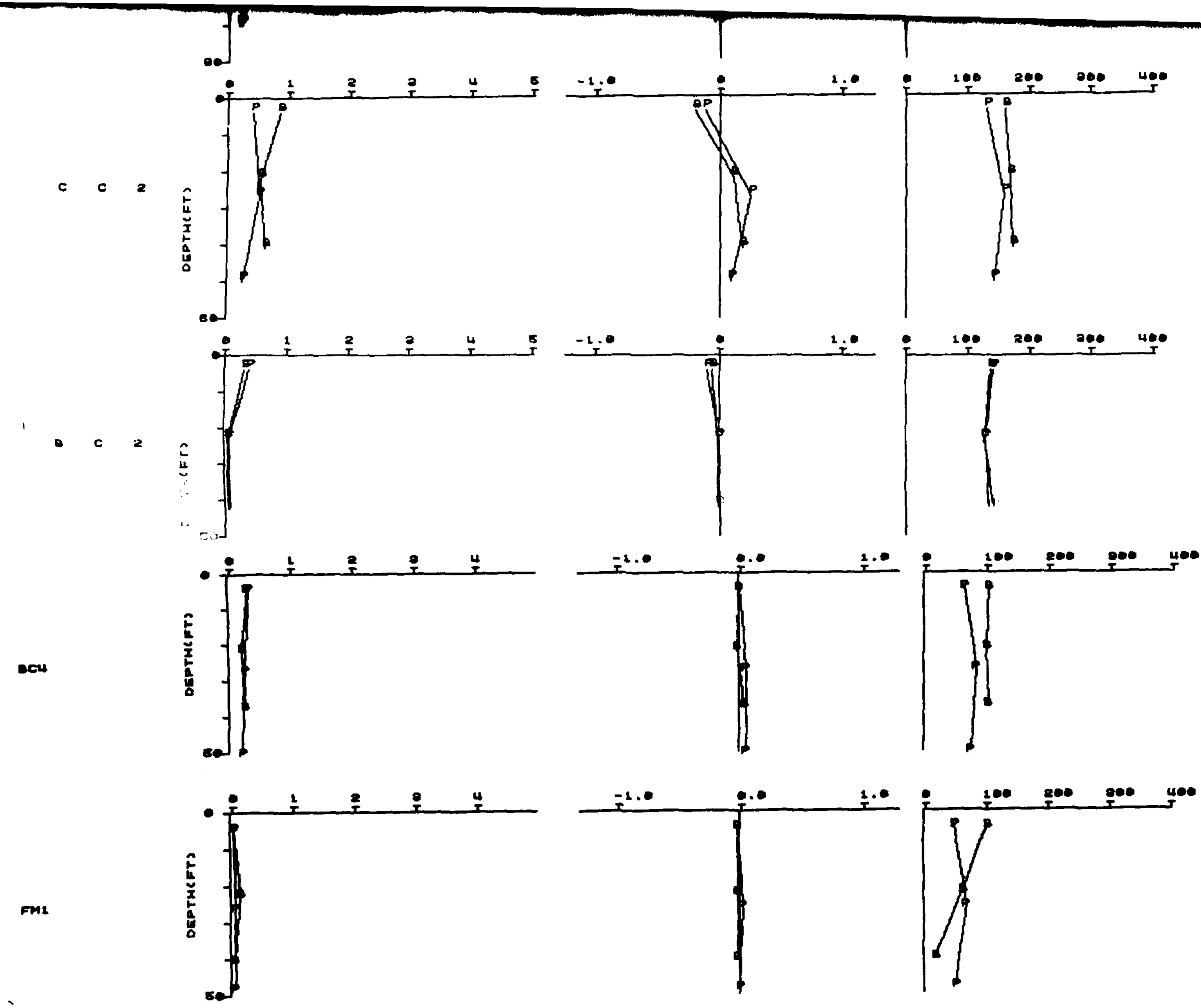


Plate 28. Vertical phase, amplitude, and offset during 120,000-cfs neap tide test



ap tide test

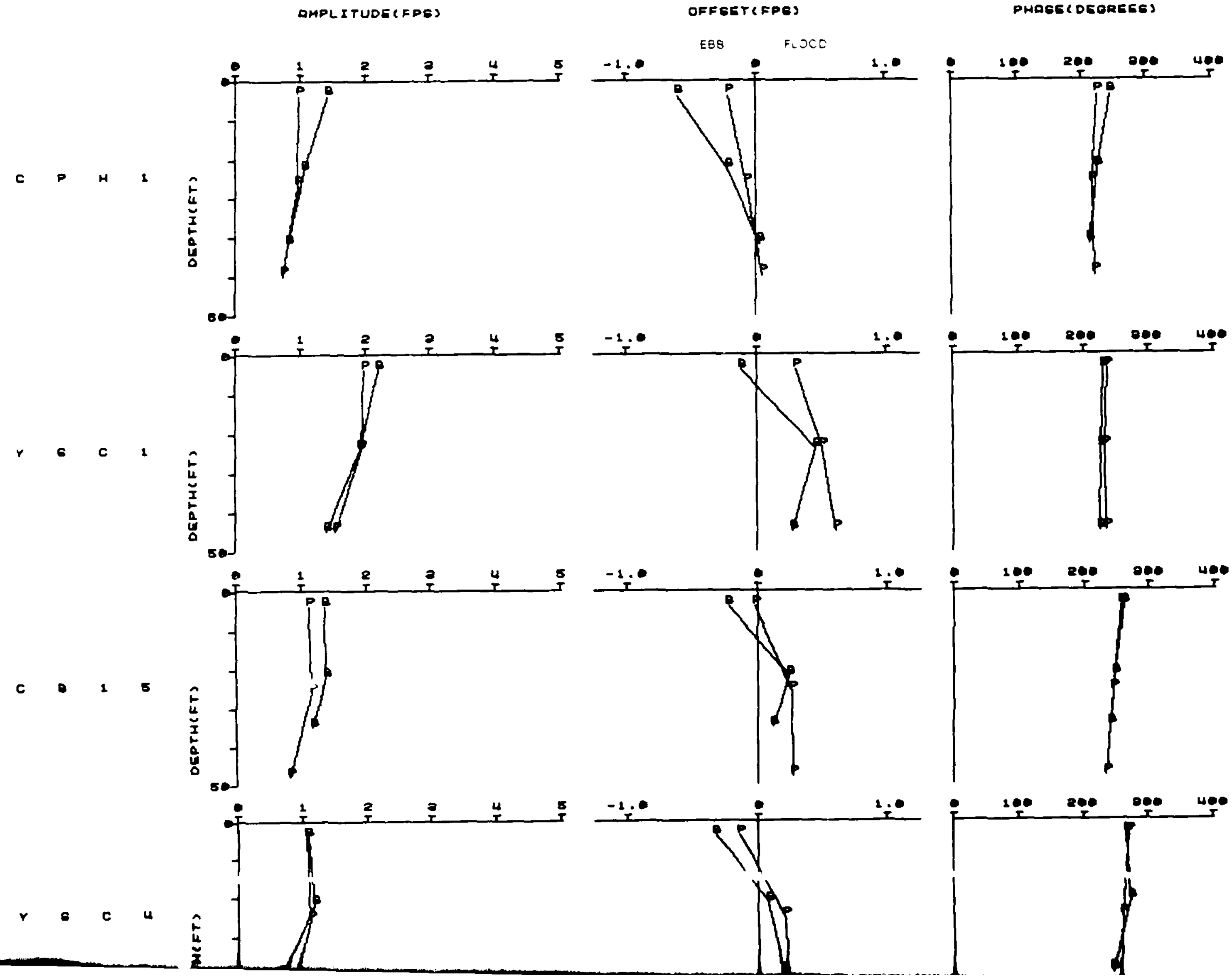

C C 2
B C 2
BC4
FM1
DEPTH(FT)
0
1
2
3
4
5
-1.0
0.0
1.0
100
200
300
400
50

PLAN AND BASE PHASE, OFFSET, AMPLITUDE

NEAP 30000

KEY

P = PLAN
B = BASE



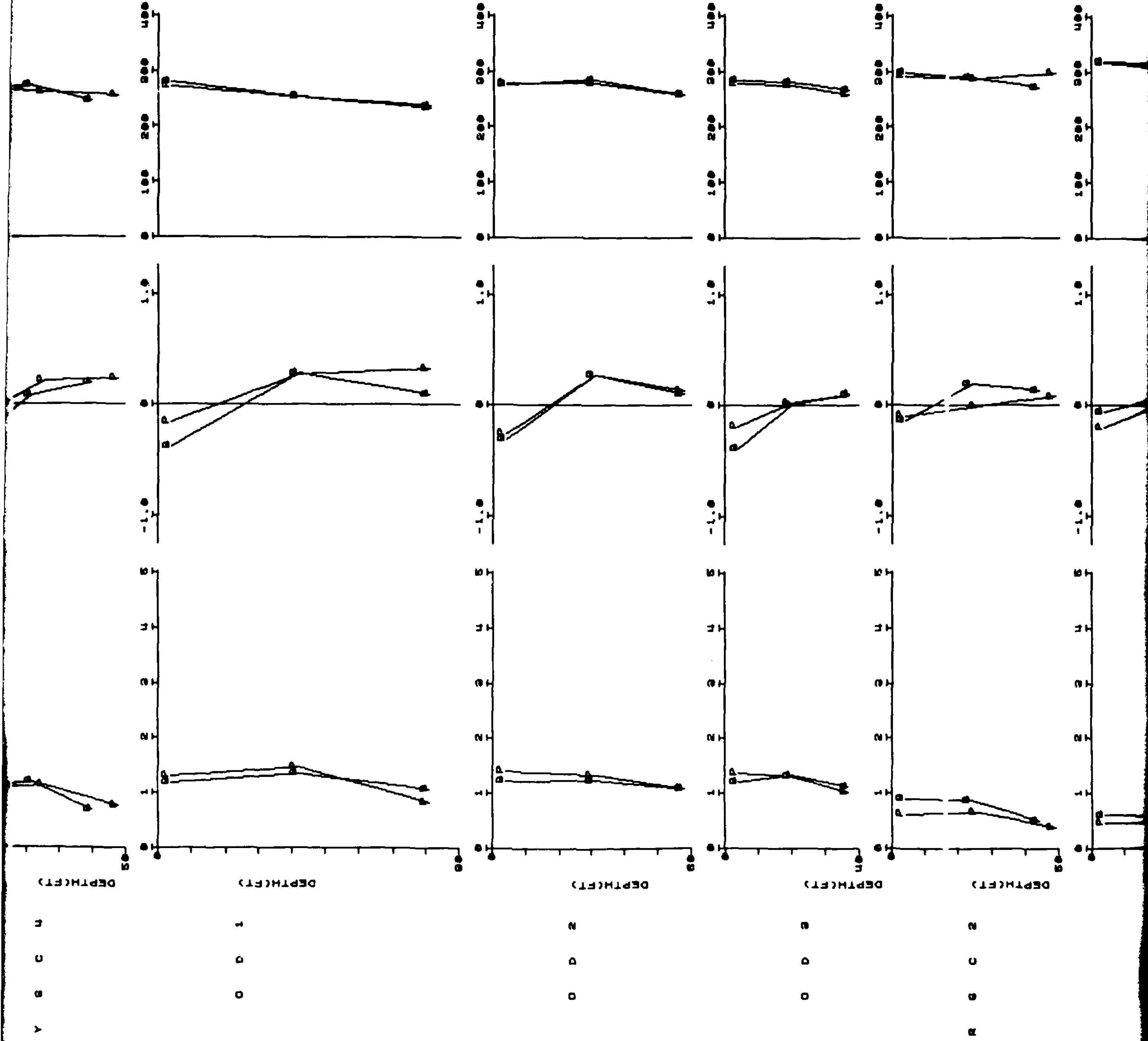
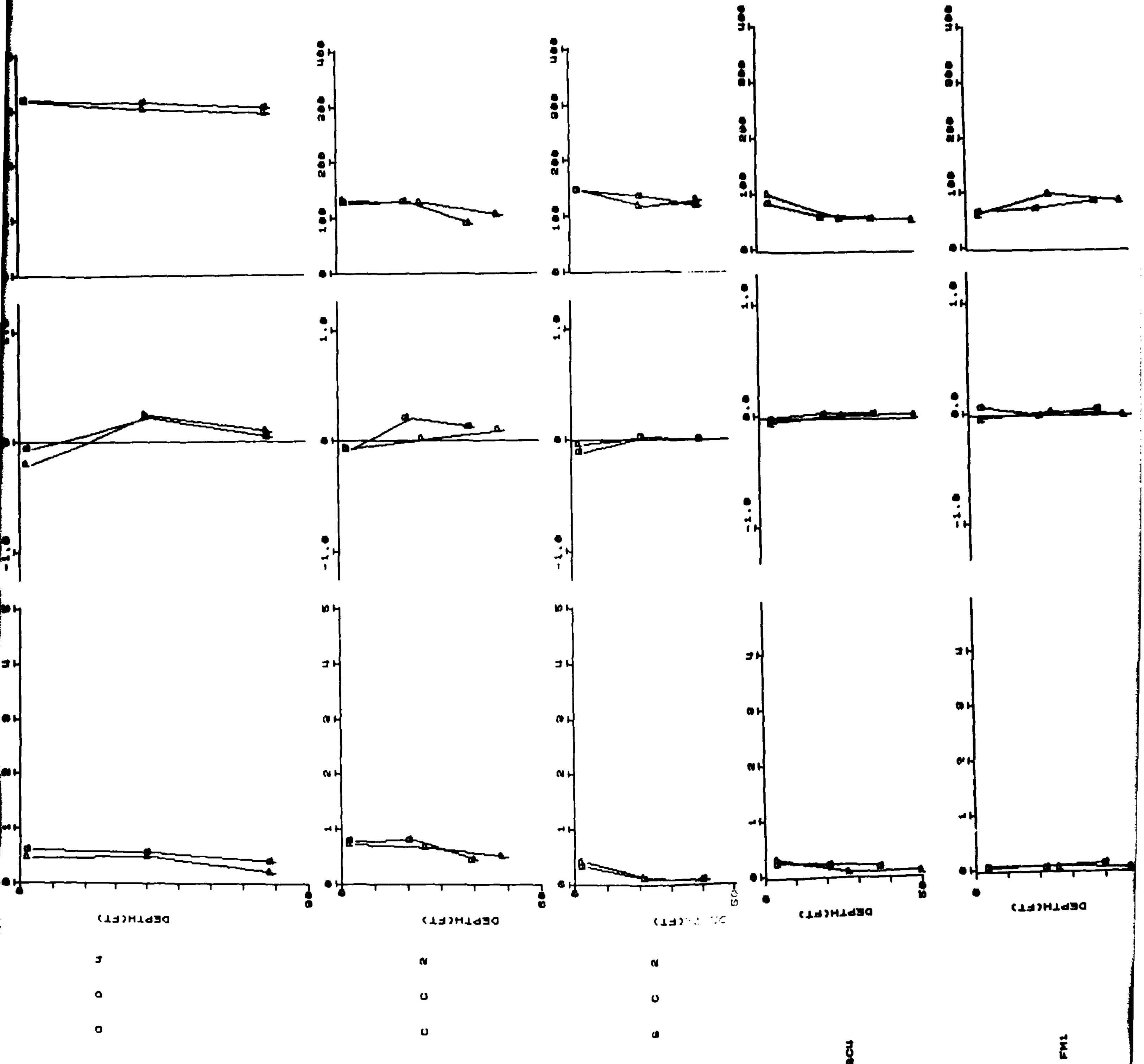


Plate 29. Vertical phase, amplitude, and offset during 30,000-cfs neap tide test



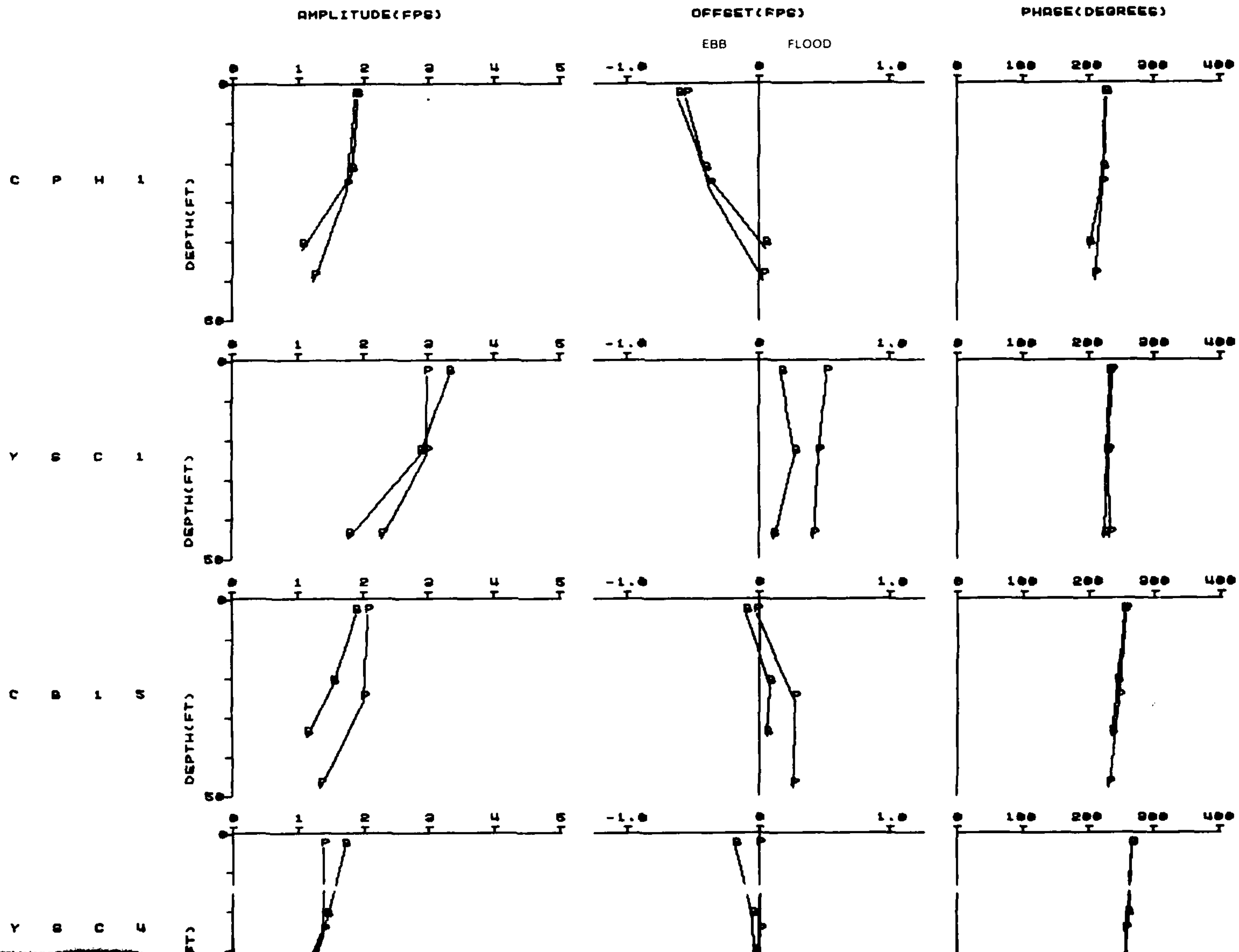
e test

PLAN AND BASE PHASE. OFFSET. AMPLITUDE

SPRING 30000

KEY

P = PLAN
B = BASE



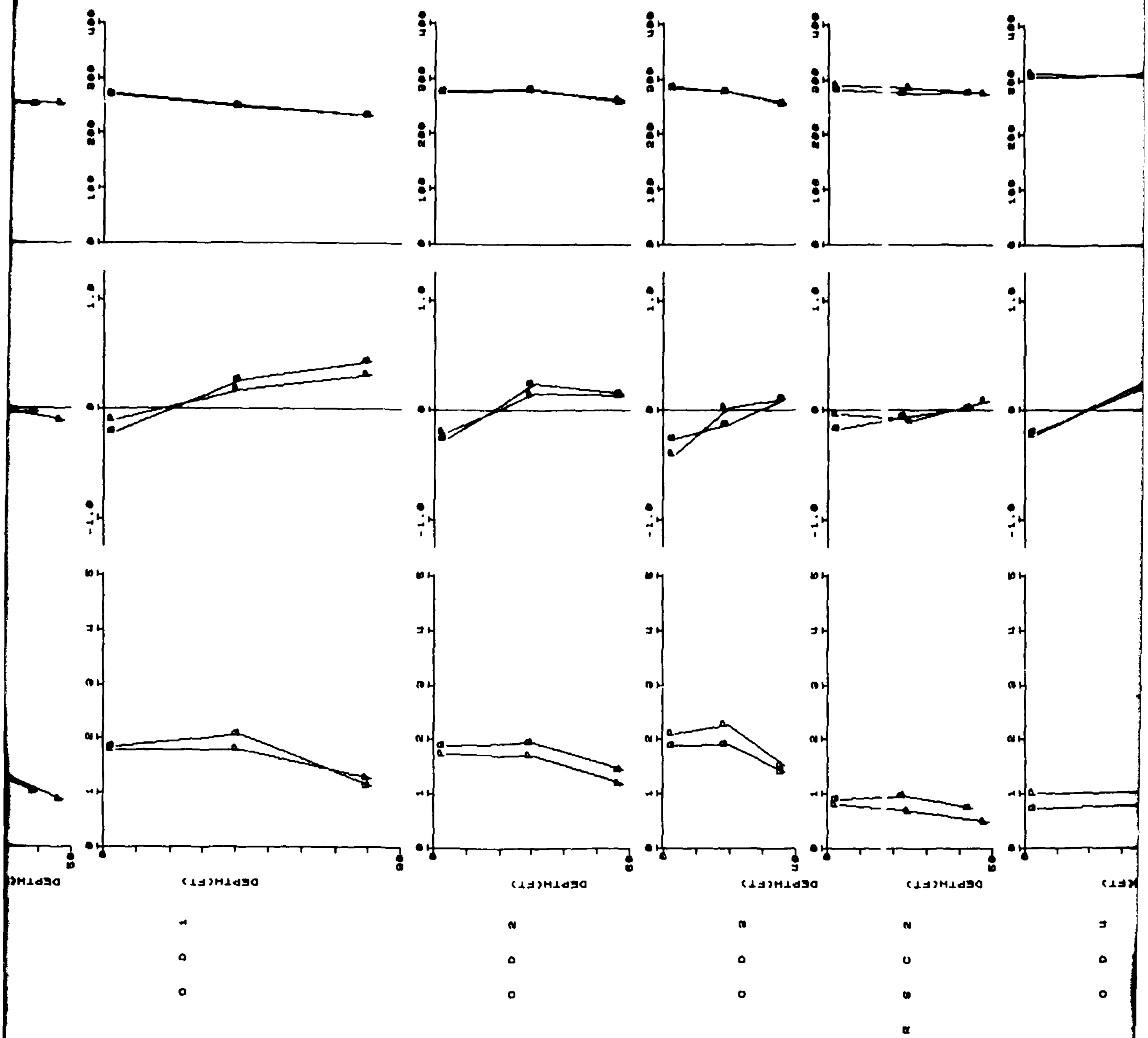
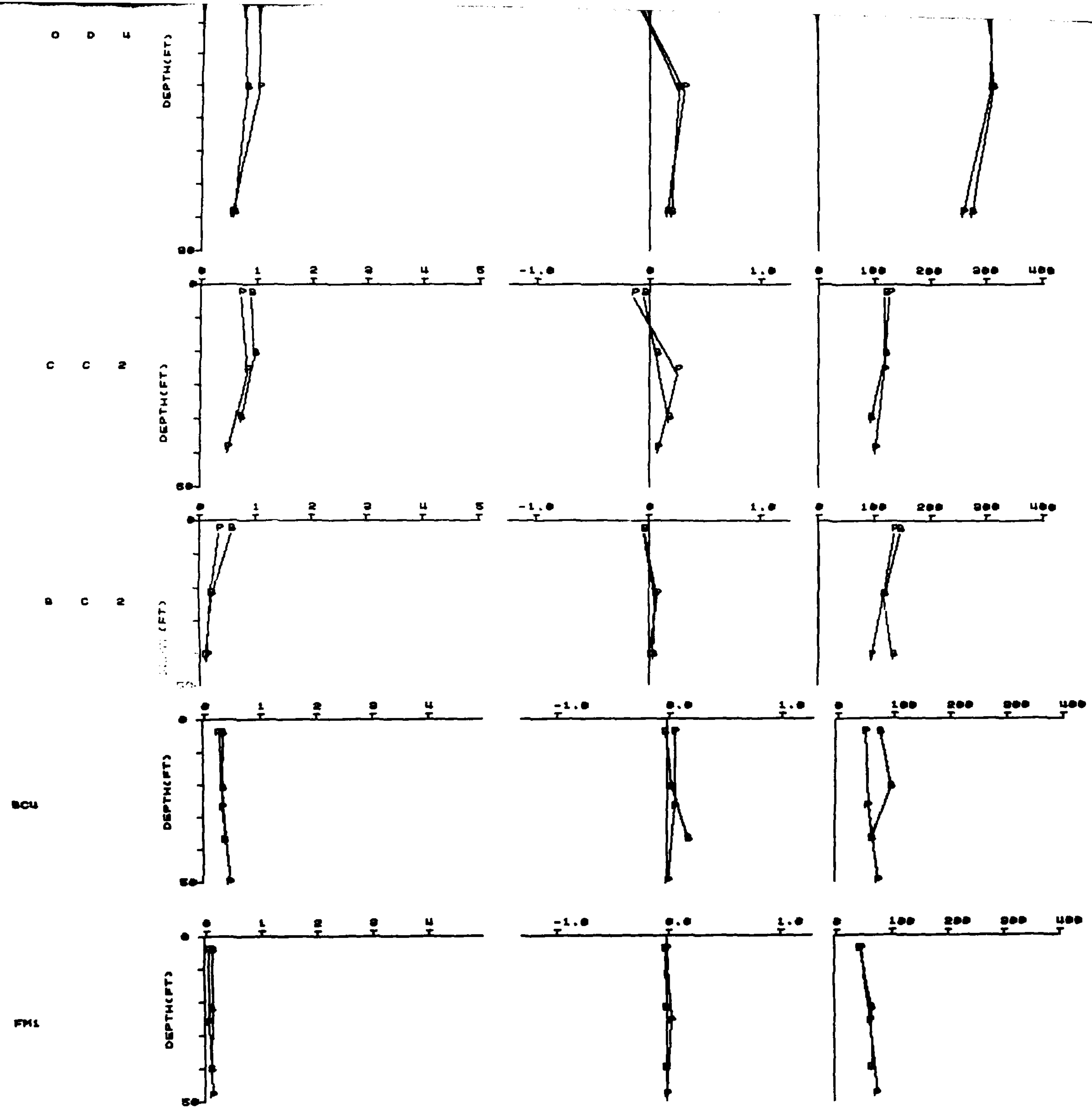
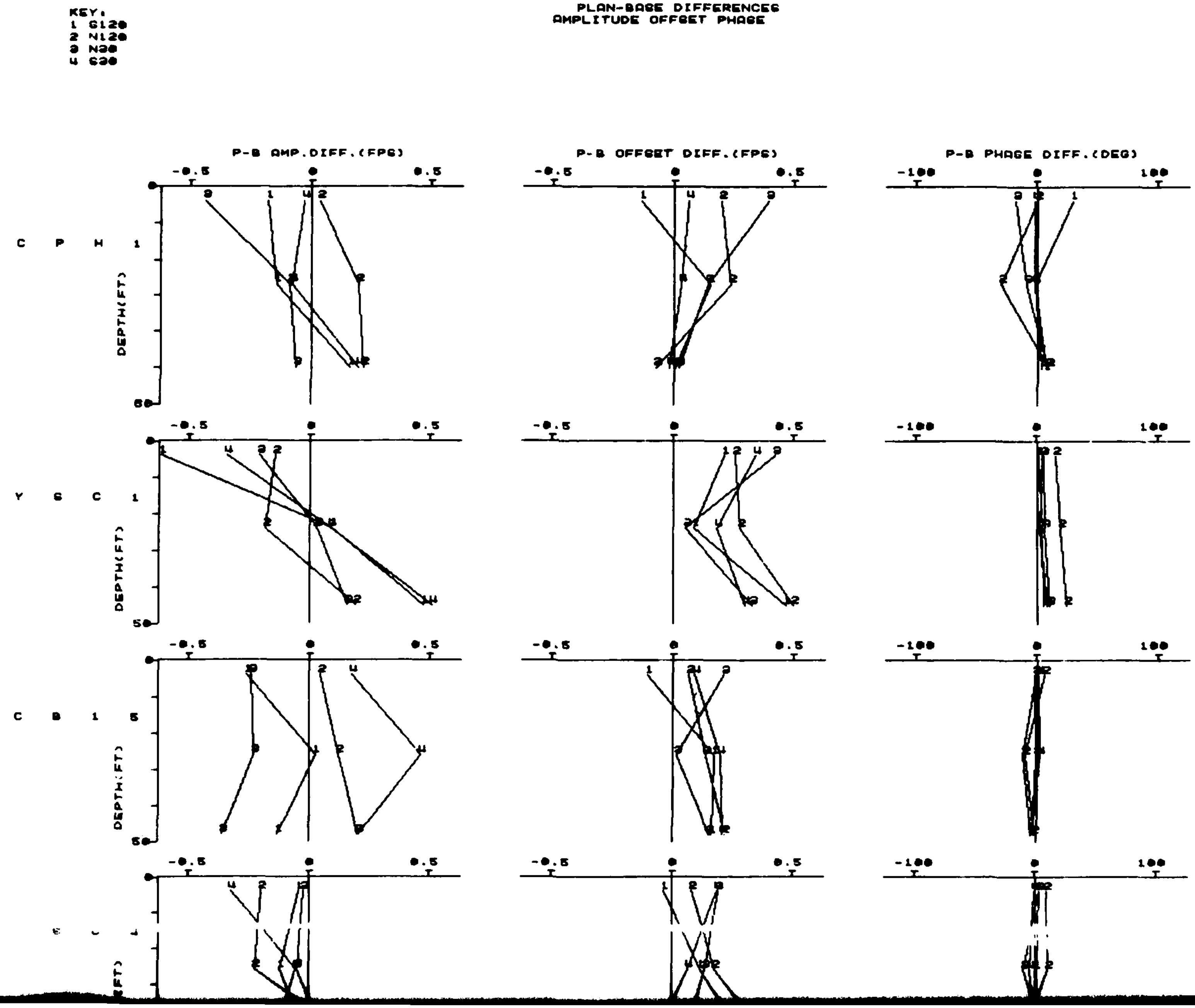


Plate 30. Vertical phase, amplitude, and offset during 30,000-cfs spring tide test



O D 4
C C 2
B C 2
SC4
FM1
DEPTH(FT)

PLAN-BASE DIFFERENCES
AMPLITUDE OFFSET PHASE



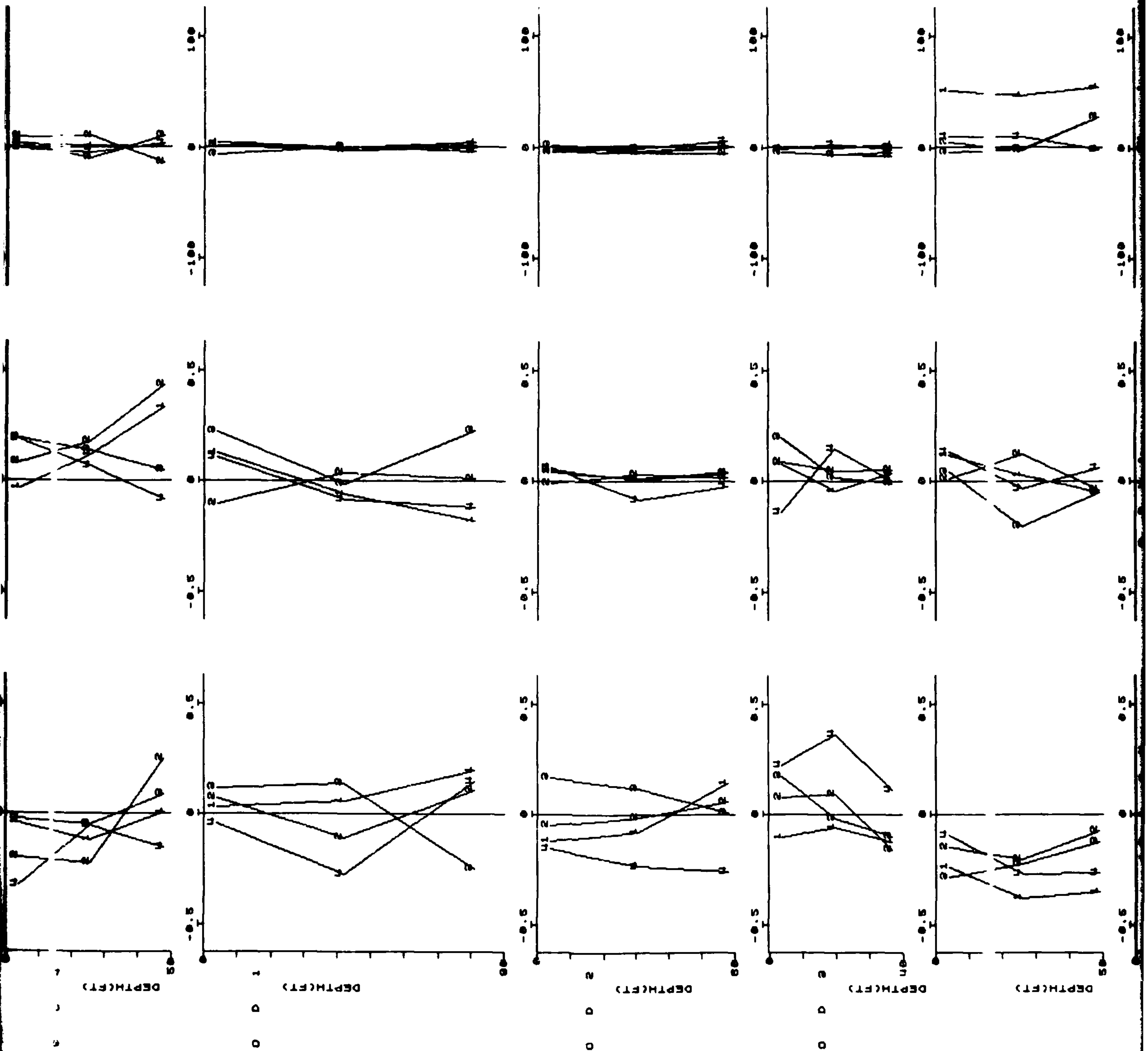
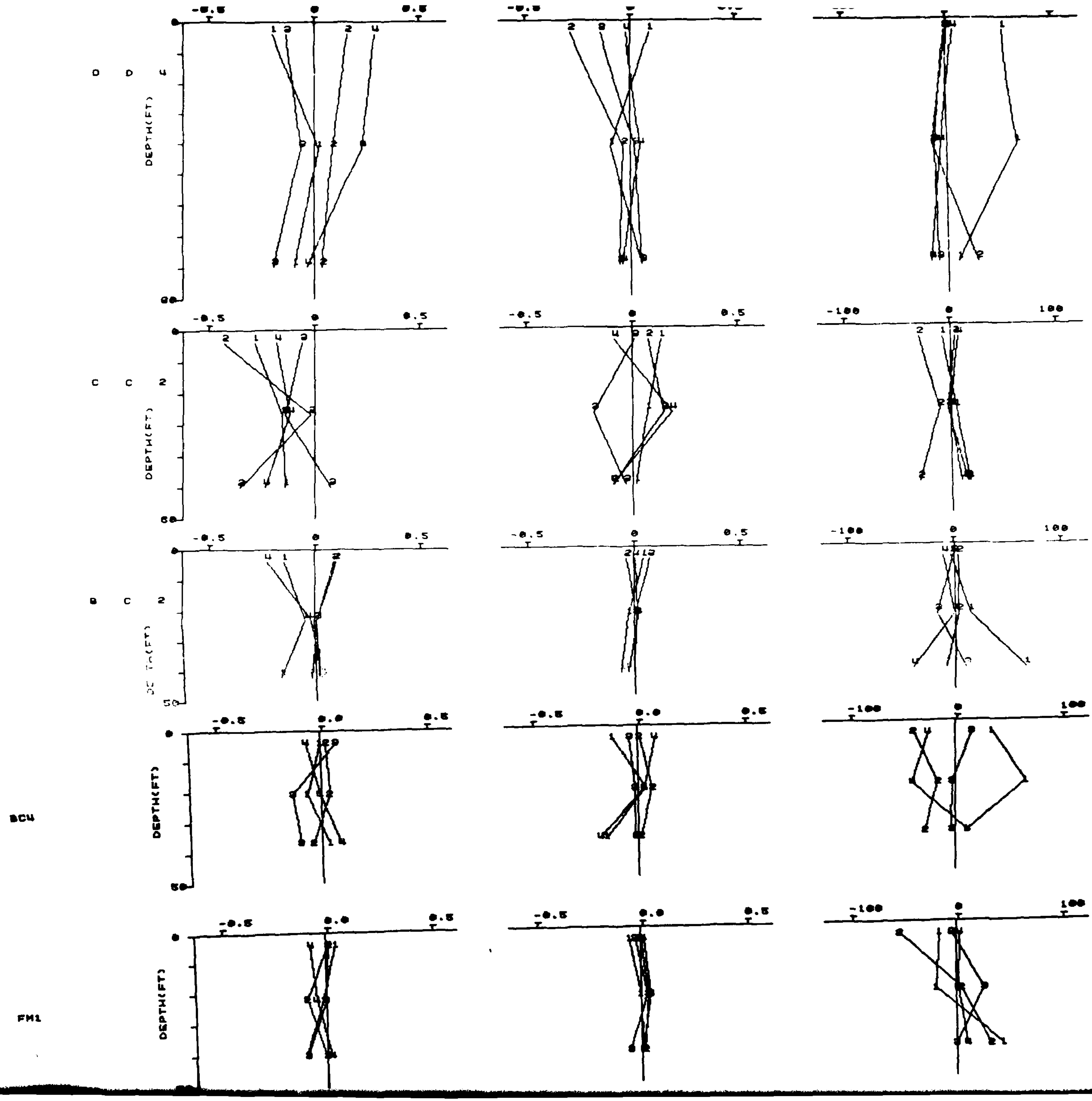
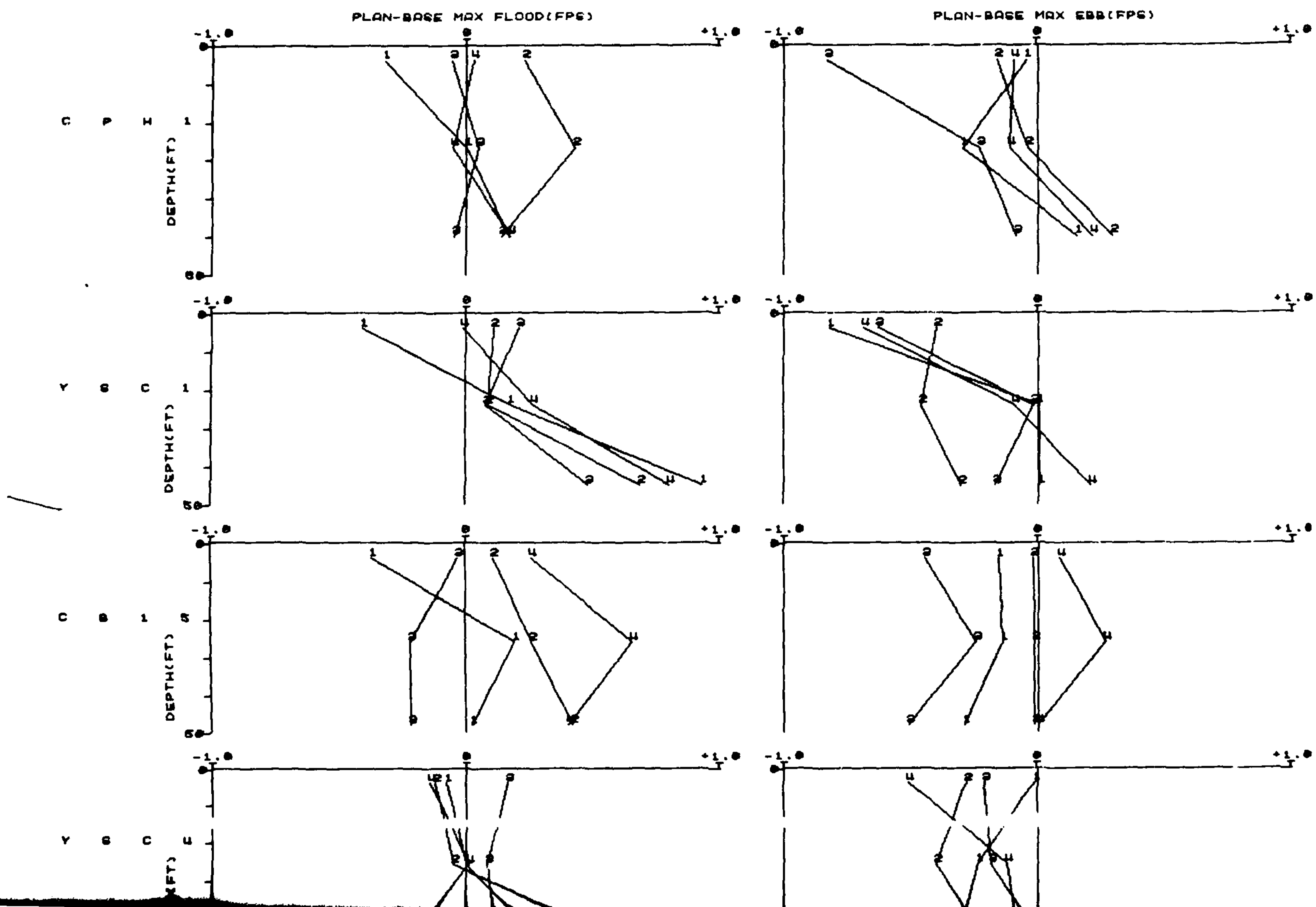


Plate 31. Vertical plan minus base phase, amplitude, and offset differenc

ces



MAXIMUM VELOCITY DIFFERENCES



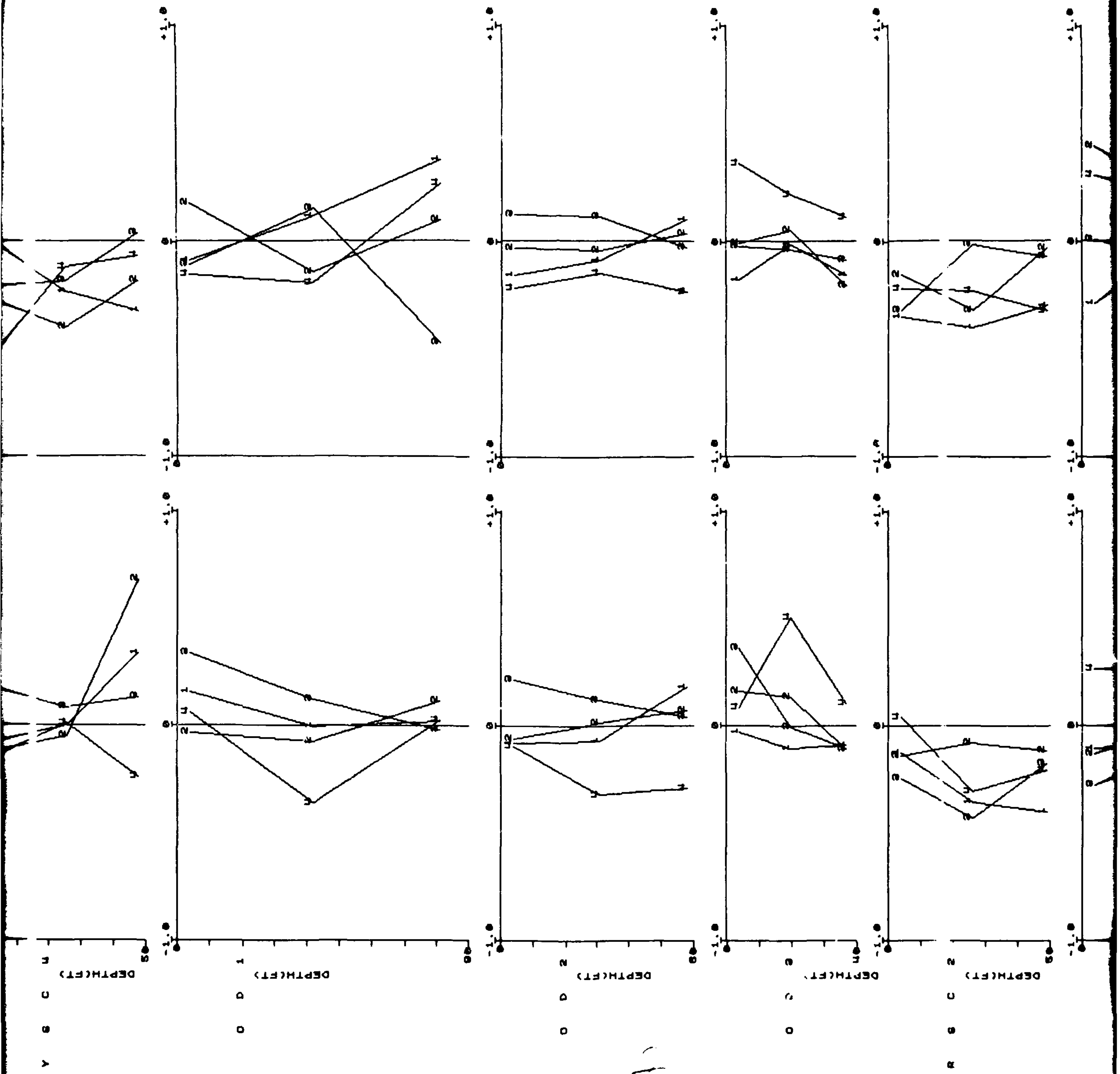
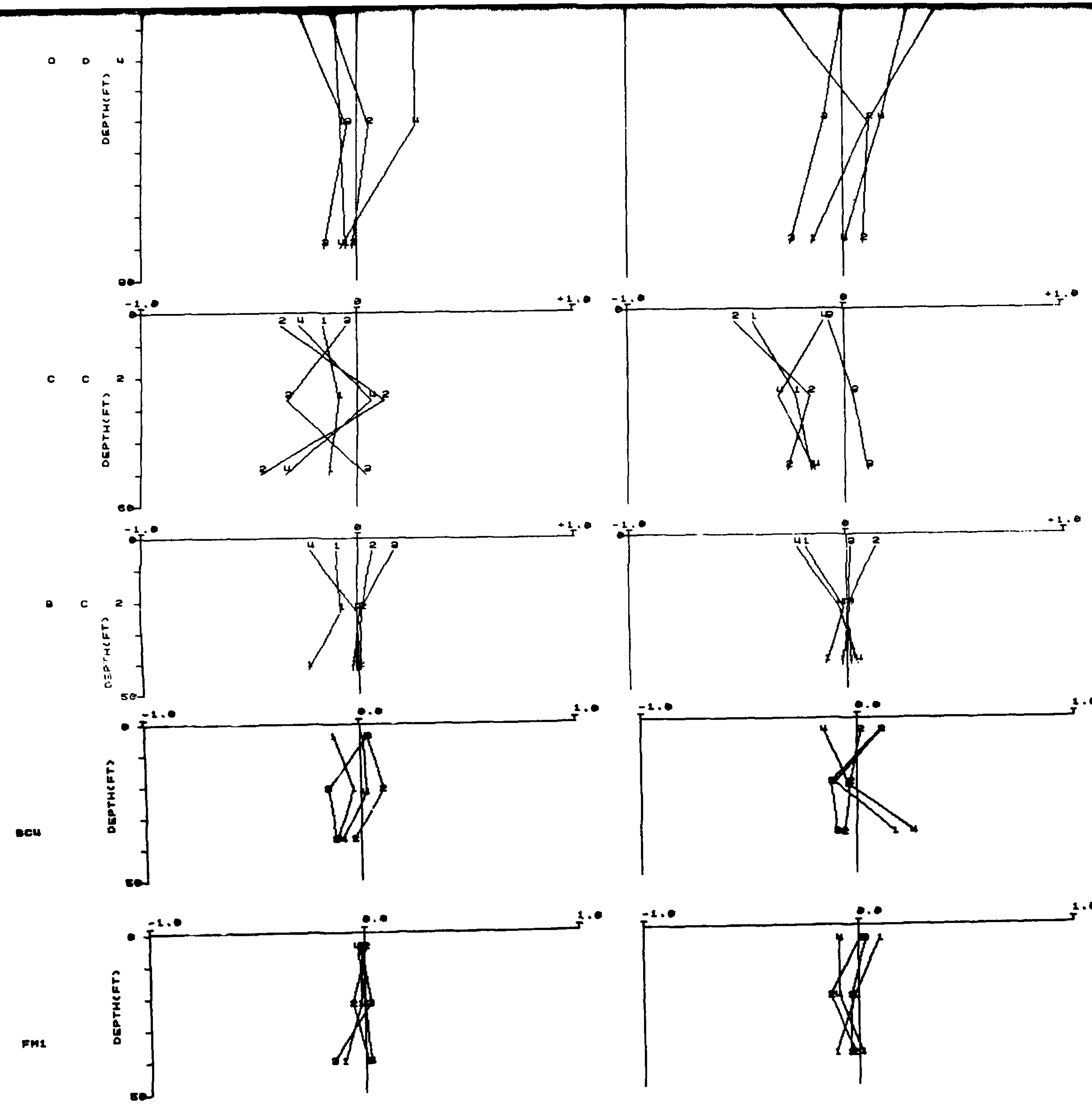


Plate 32. Vertical plan minus base maximum flood and maximum ebb differences



D D
C C
B C
BCW
FM1
DEPTH(FT)
-1.0
0
+1.0
0.0
1.0

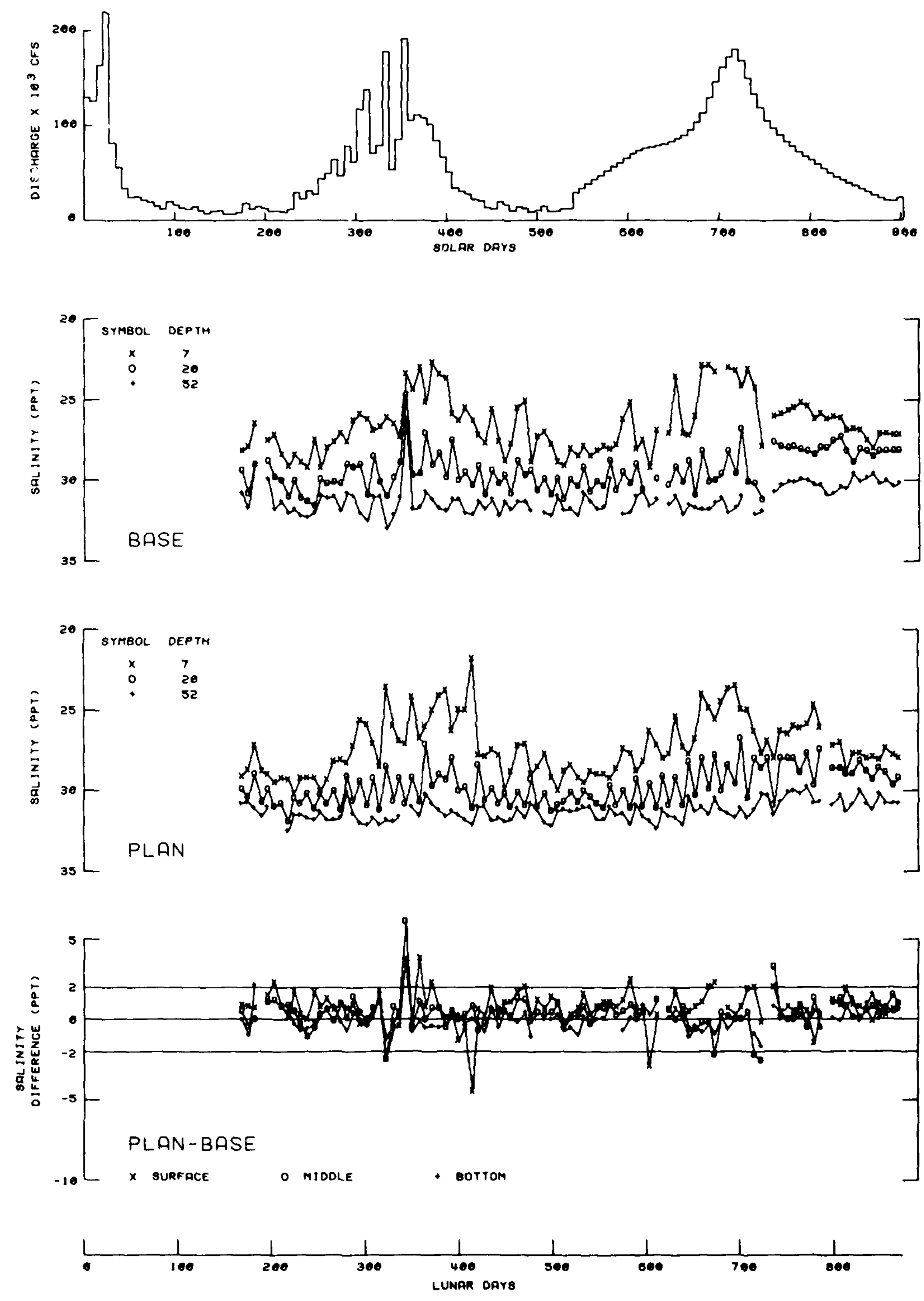


Plate 33. Sta CB-O-1 salinity time-history

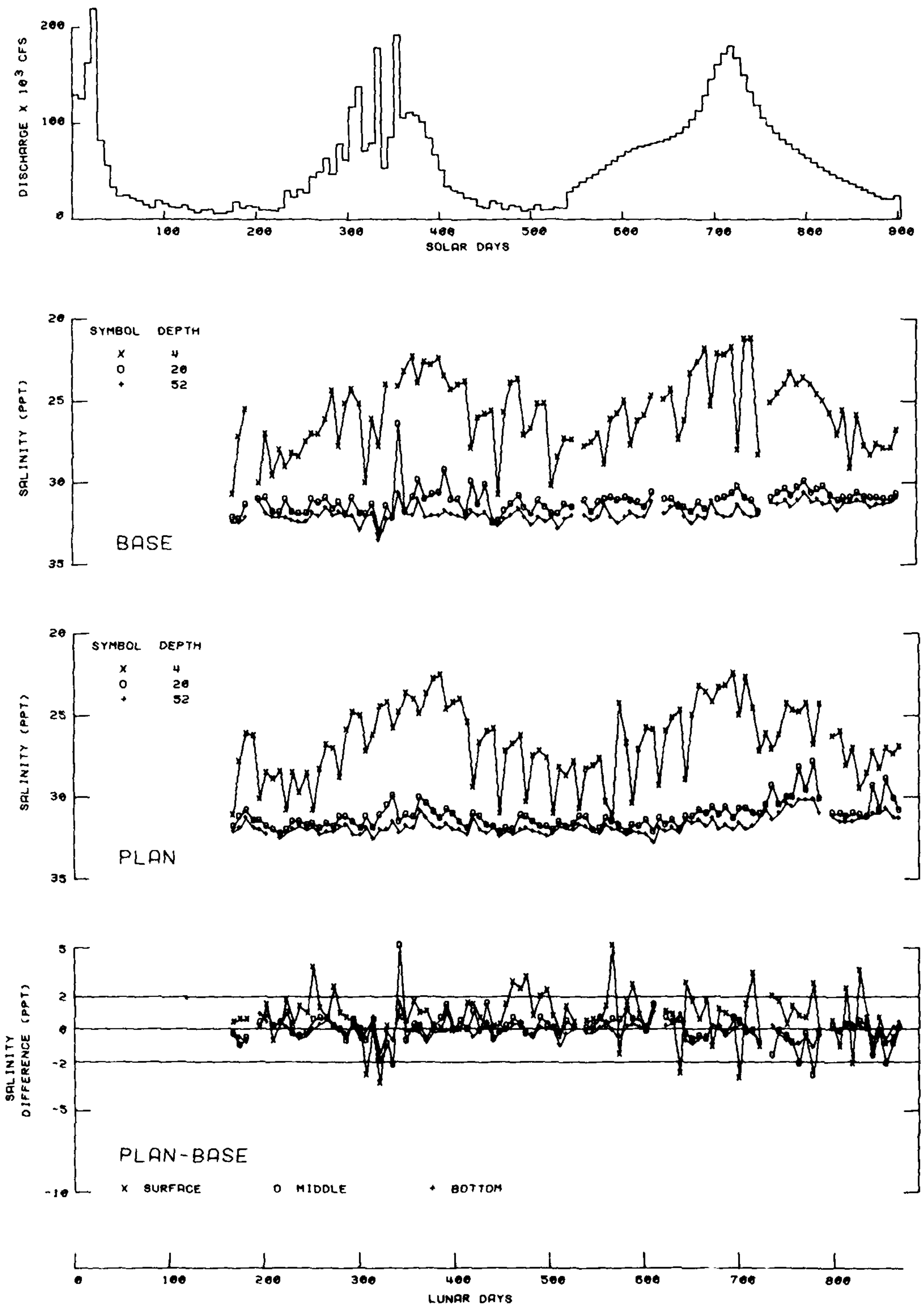


Plate 34. Sta CB-0-2 salinity time-history

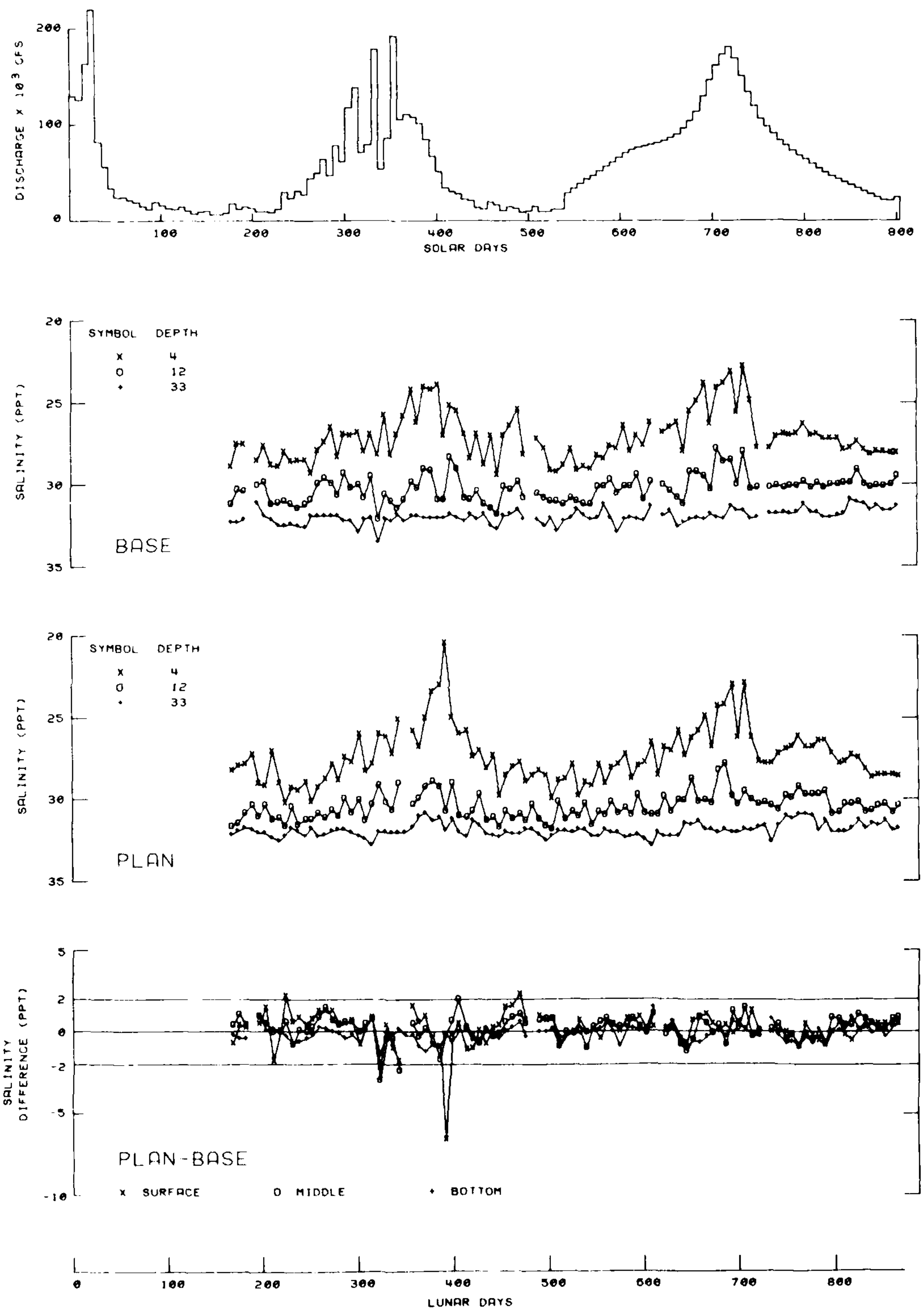


Plate 35. Sta CB-0-3 salinity time-history

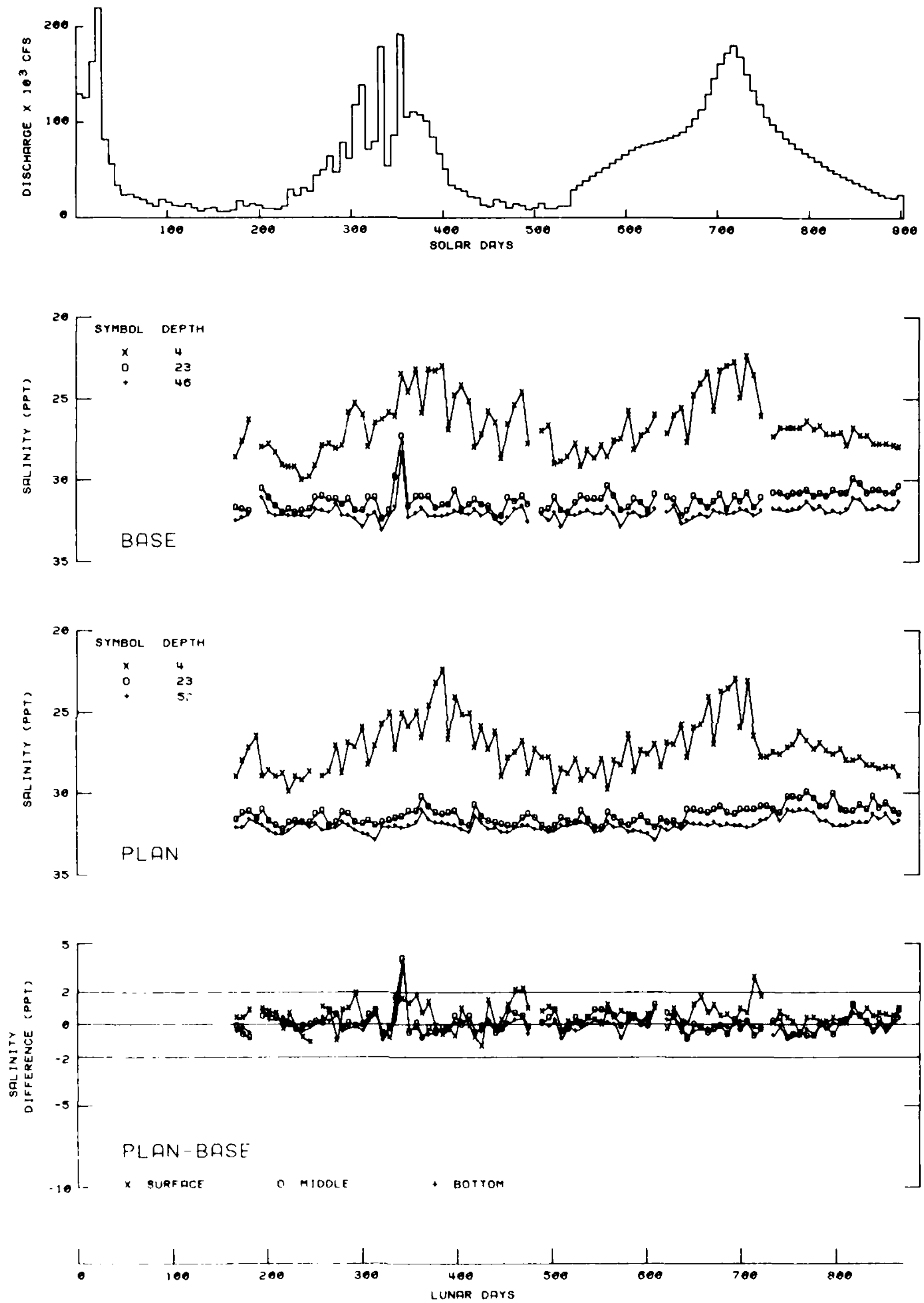


Plate 36. Sta CPH-1 salinity time-history

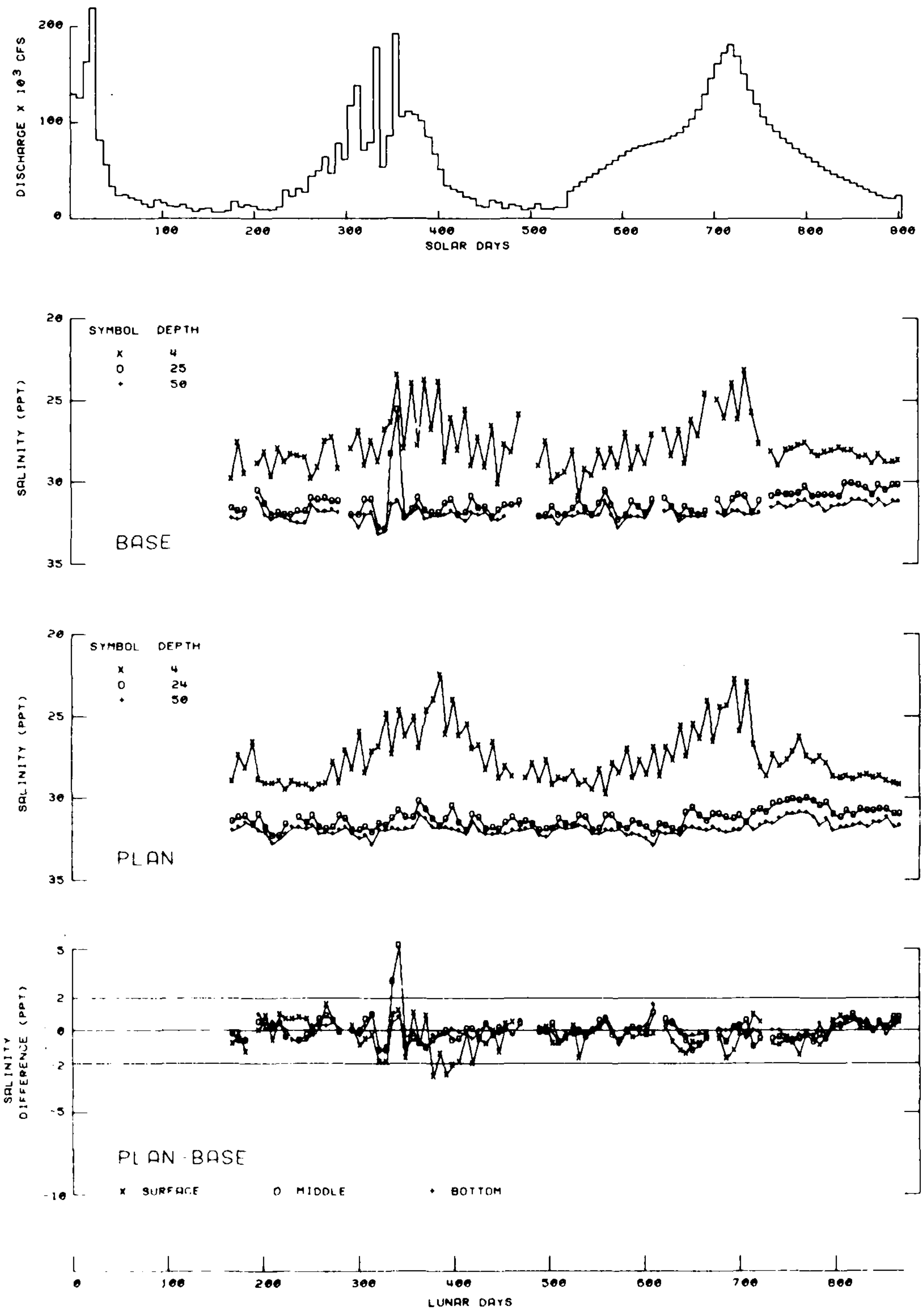


Plate 37. Sta CPH-2 salinity time-history

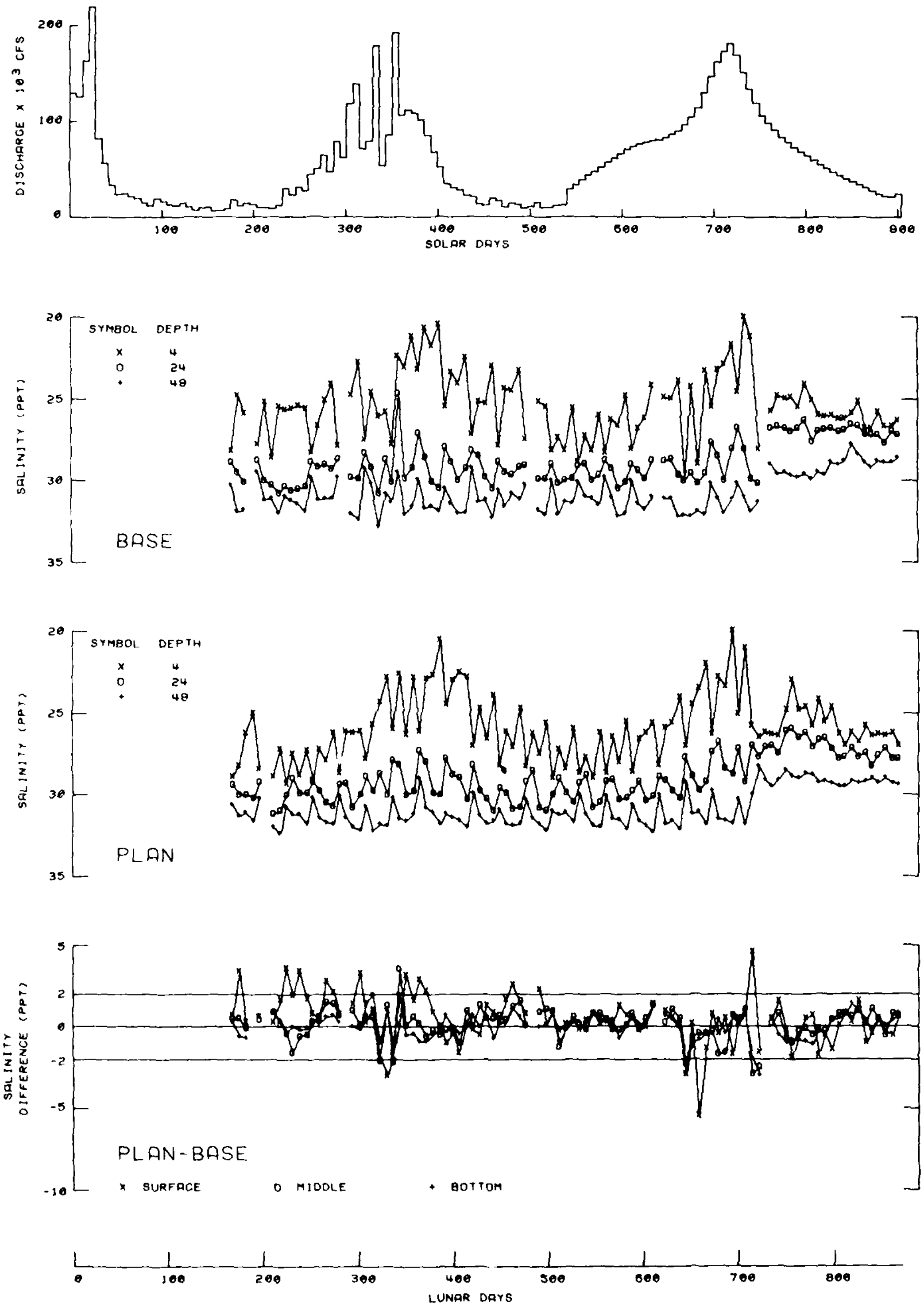


Plate 38. Sta YSC-1 salinity time-history

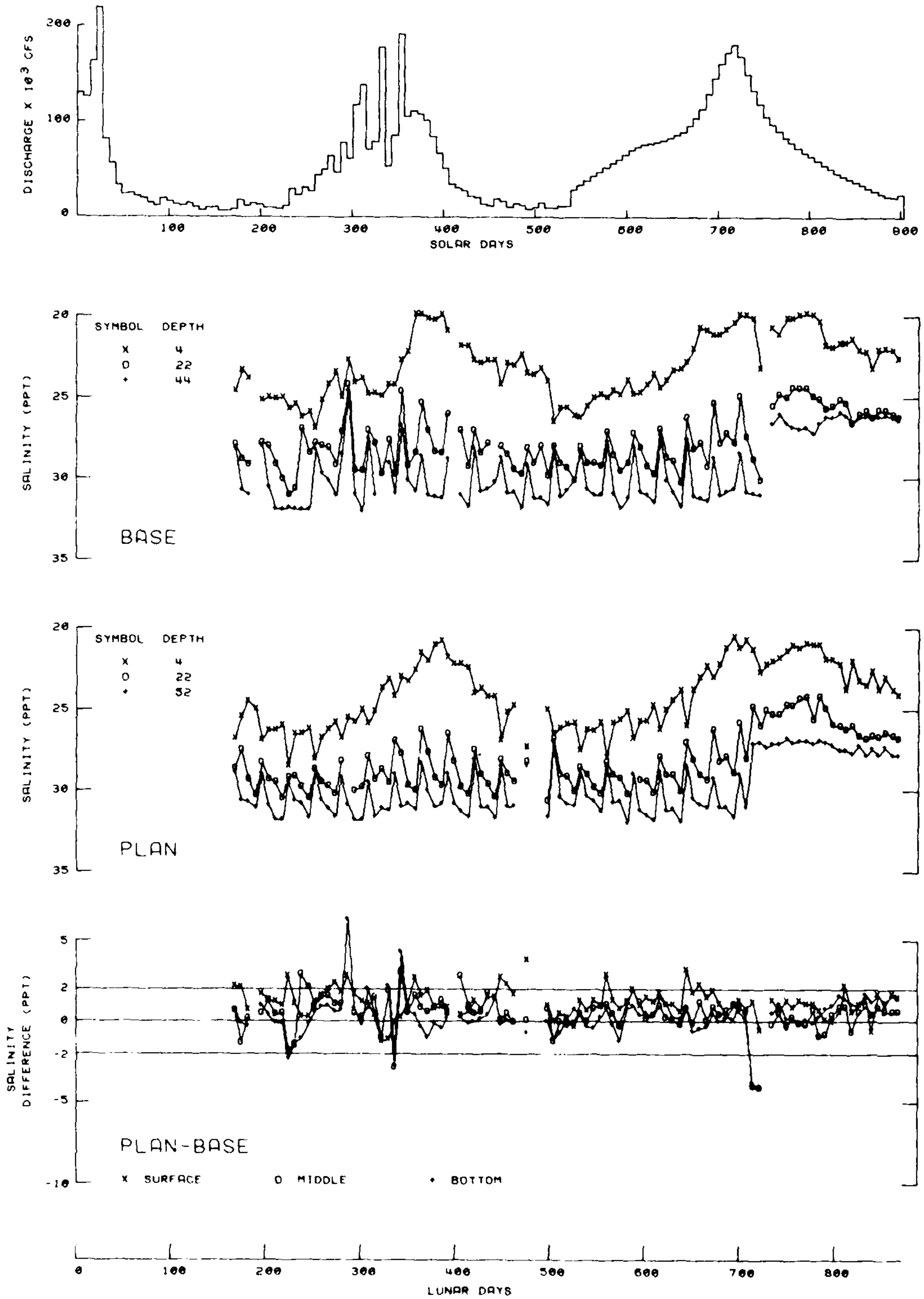


Plate 39. Sta YSC-2 salinity time-history

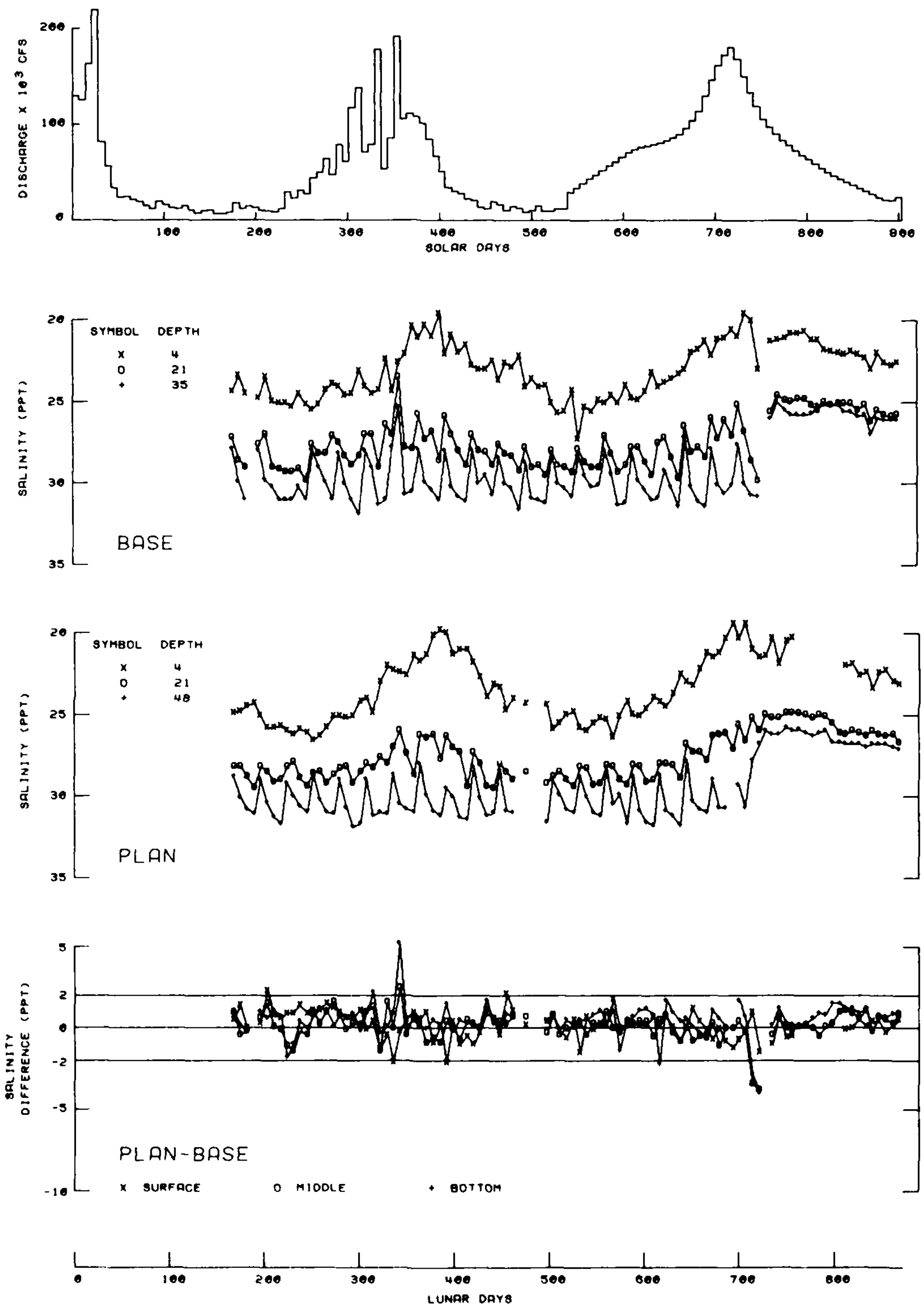


Plate 40. Sta CB-1-5 salinity time-history

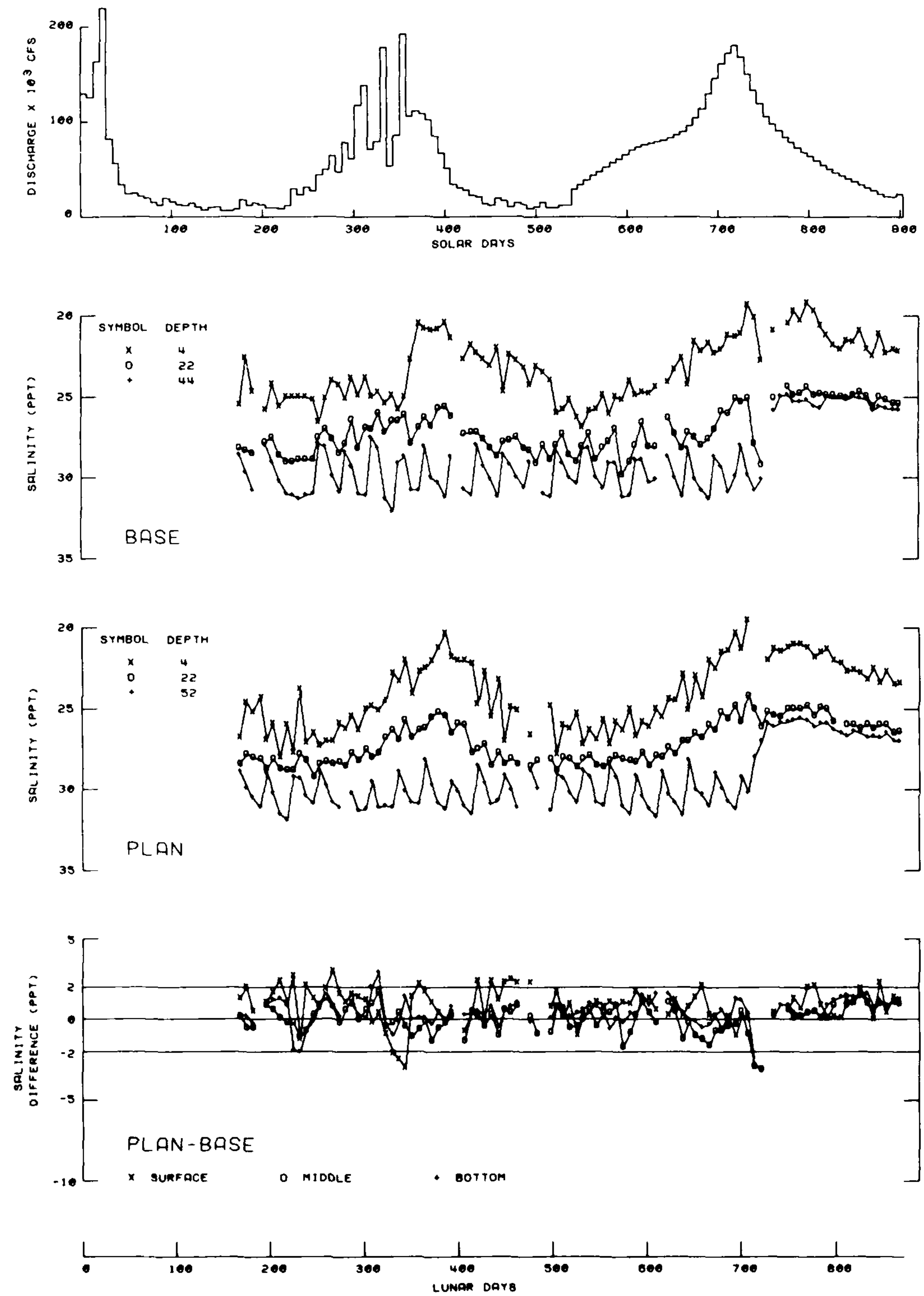


Plate 41. Sta YSC-3 salinity time-history

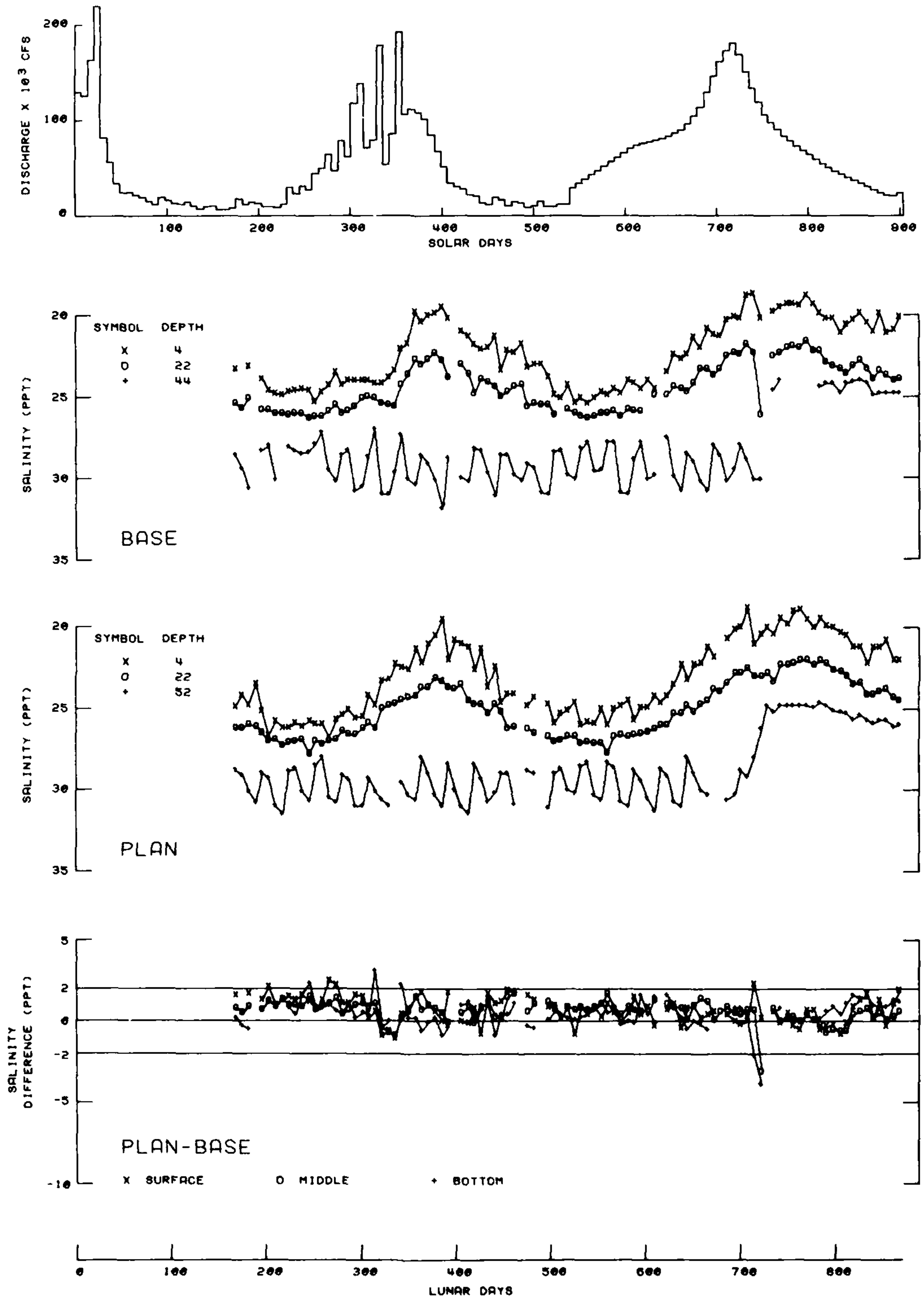


Plate 42. Sta YSC-4 salinity time-history

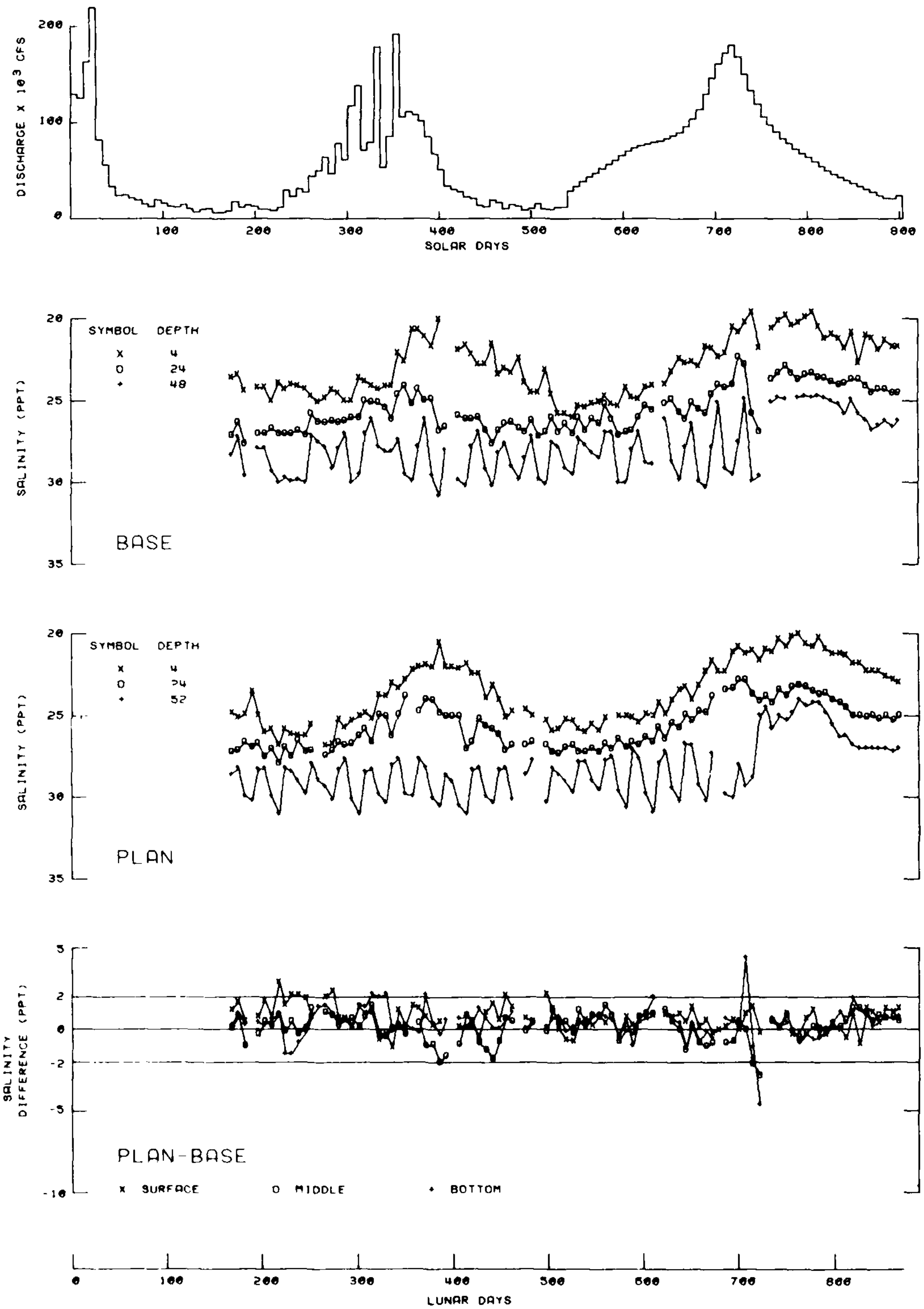


Plate 43. Sta YSC-5 salinity time-history

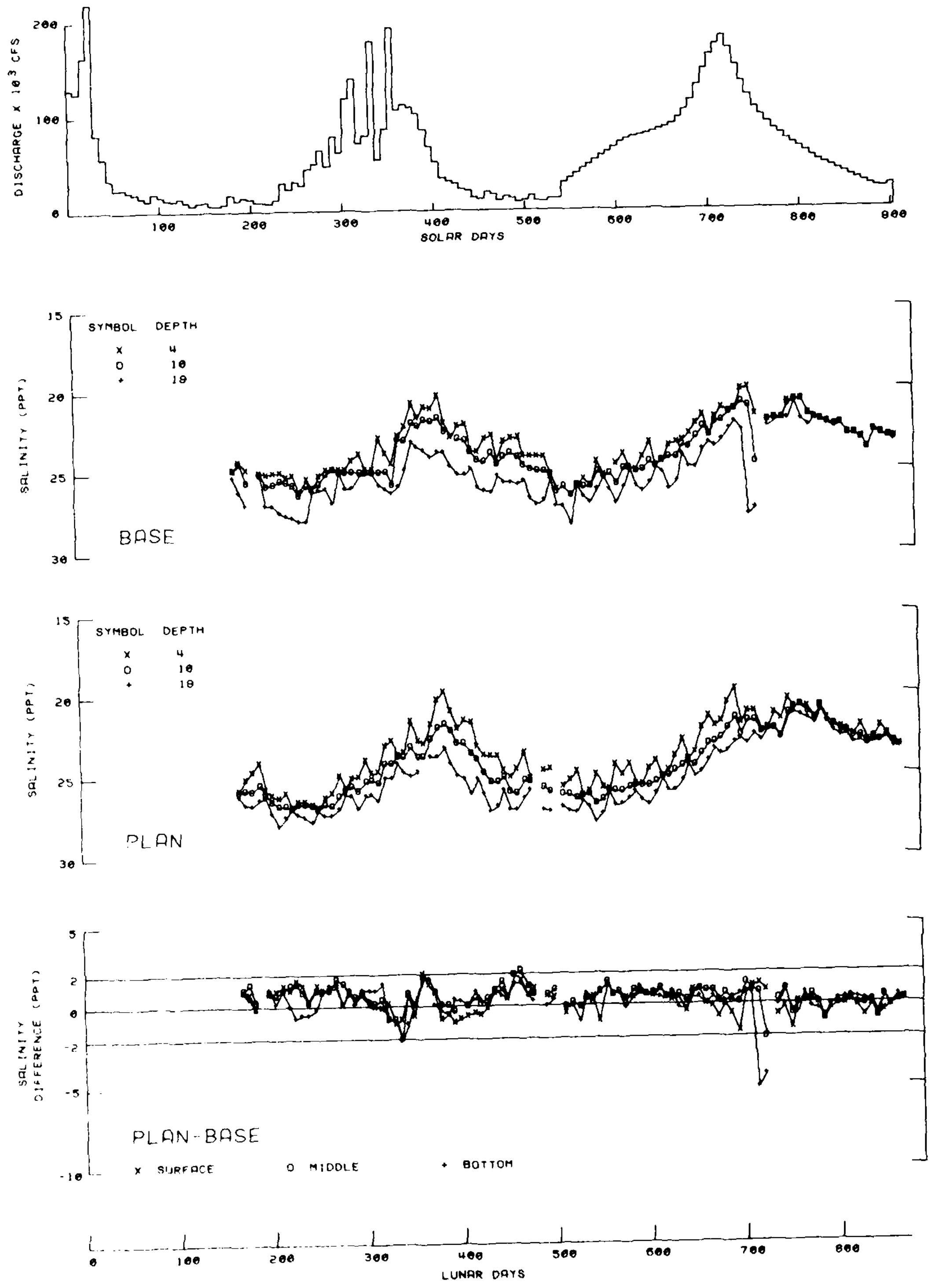


Plate 44. Sta CB-1-2 salinity time-history

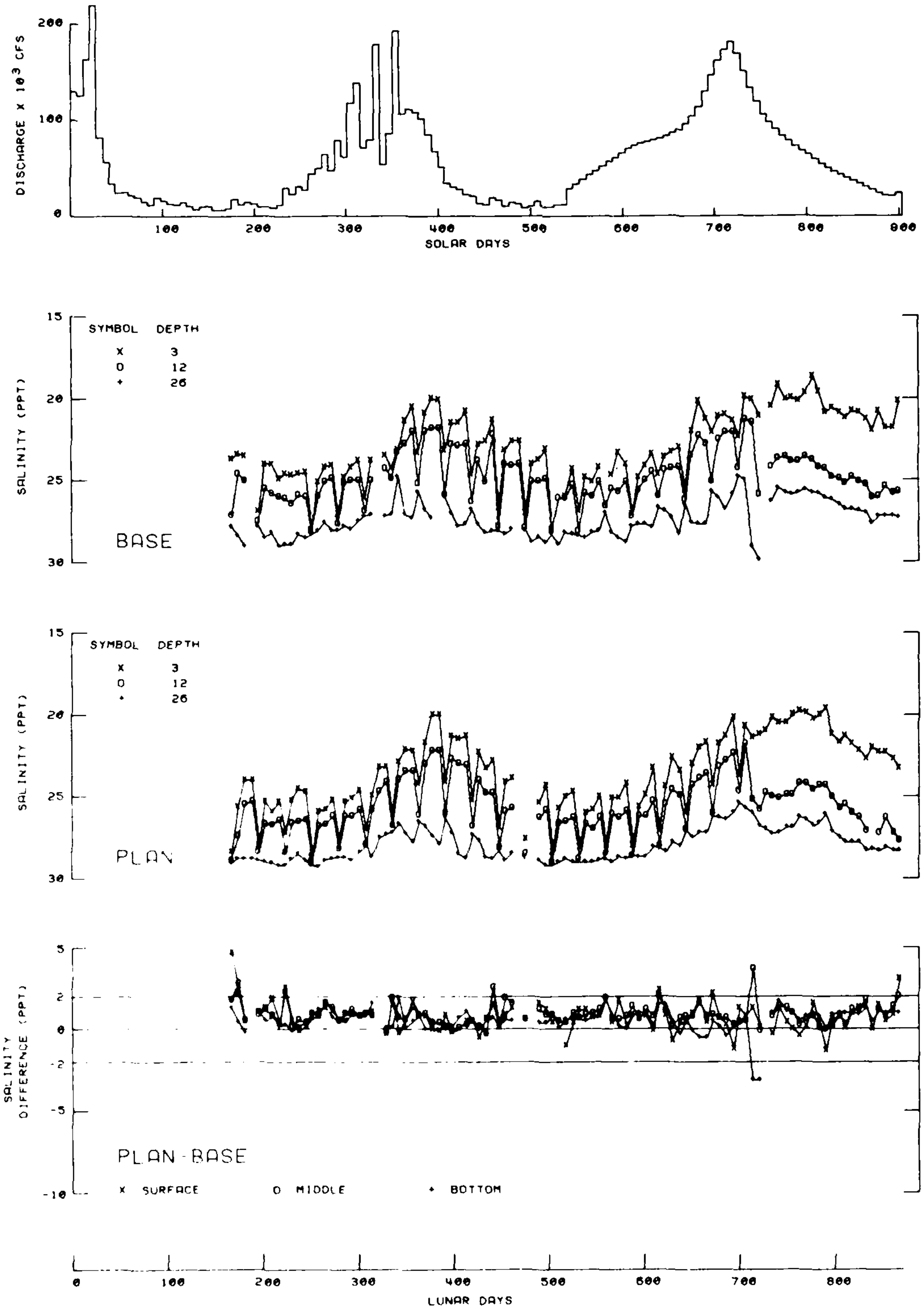


Plate 45. Sta CB-1-7 salinity time-history

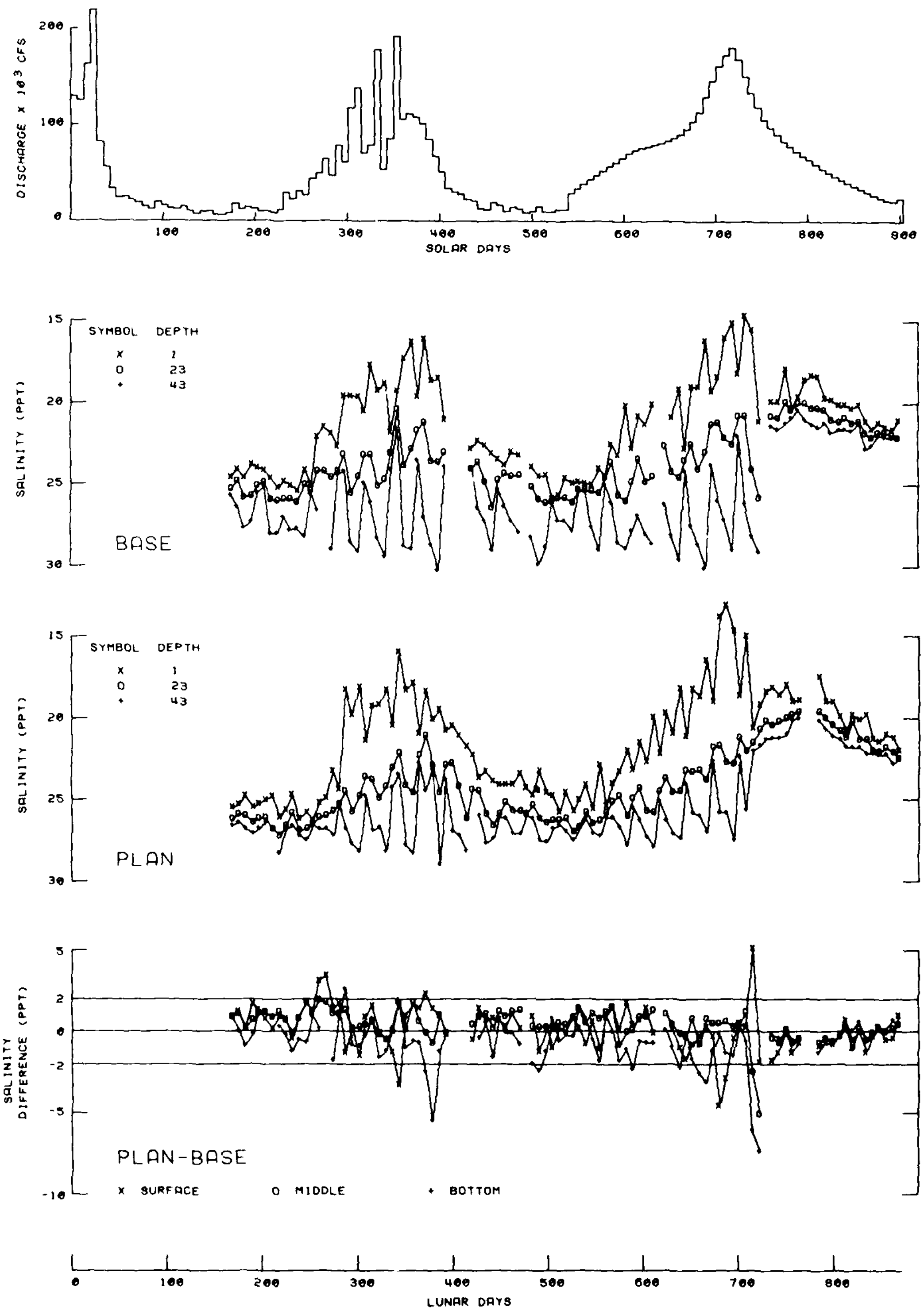


Plate 46. Sta J-1-2 salinity time-history

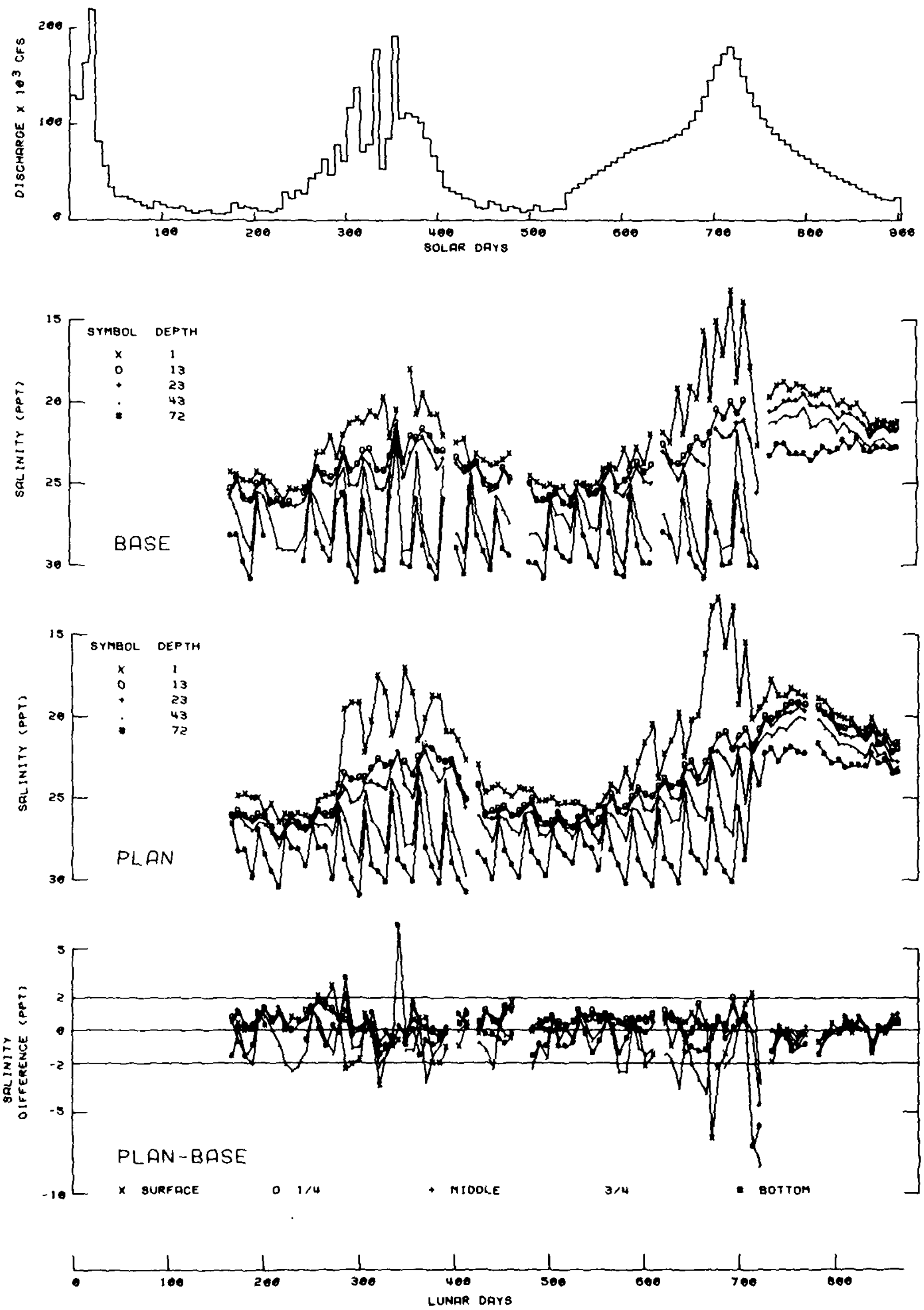


Plate 47. Sta J-1-3 salinity time-history

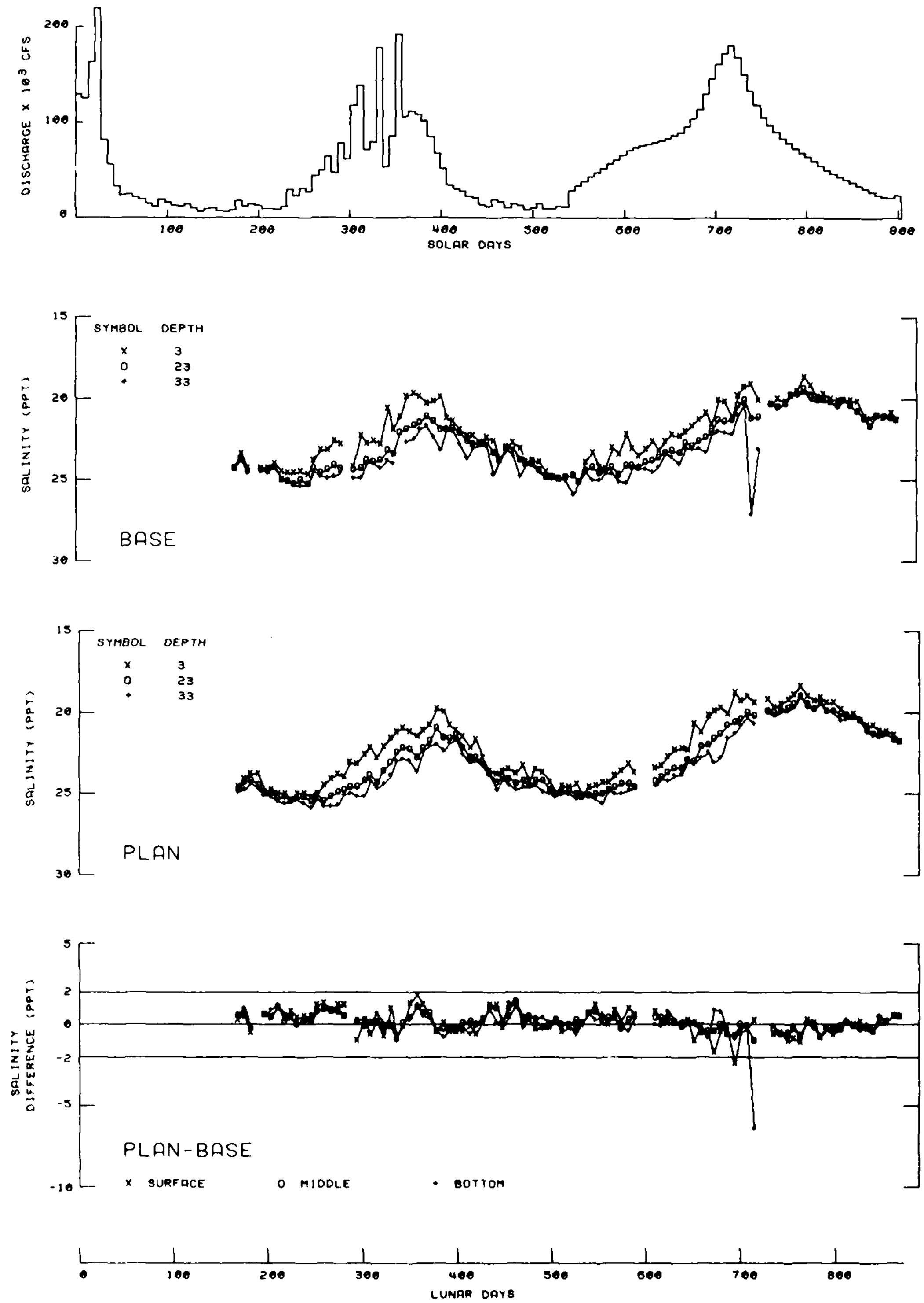


Plate 48. Sta Y-1-1 salinity time-history

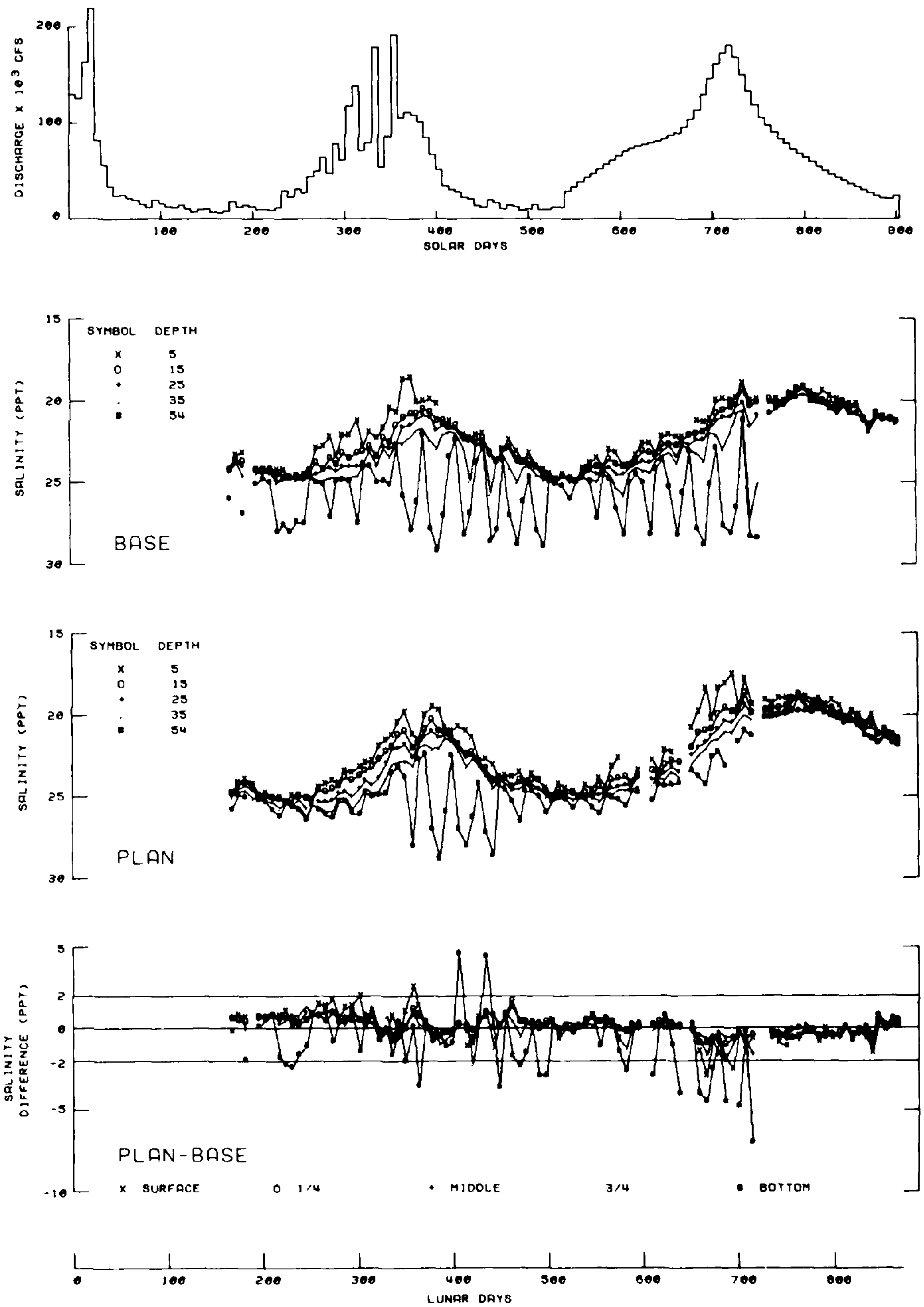


Plate 49. Sta Y-1-2 salinity time-history

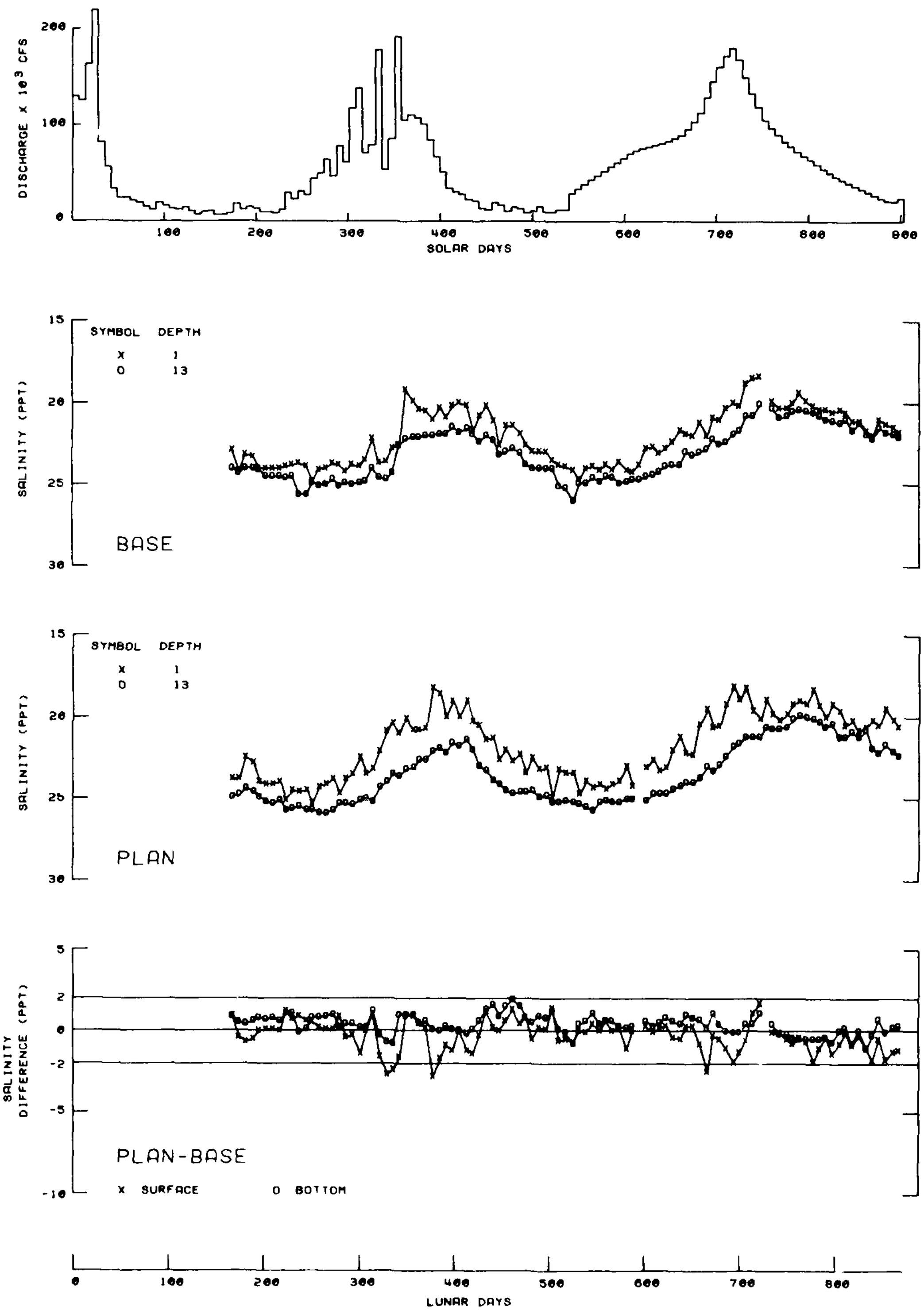


Plate 50. Sta MB-1-1 salinity time-history

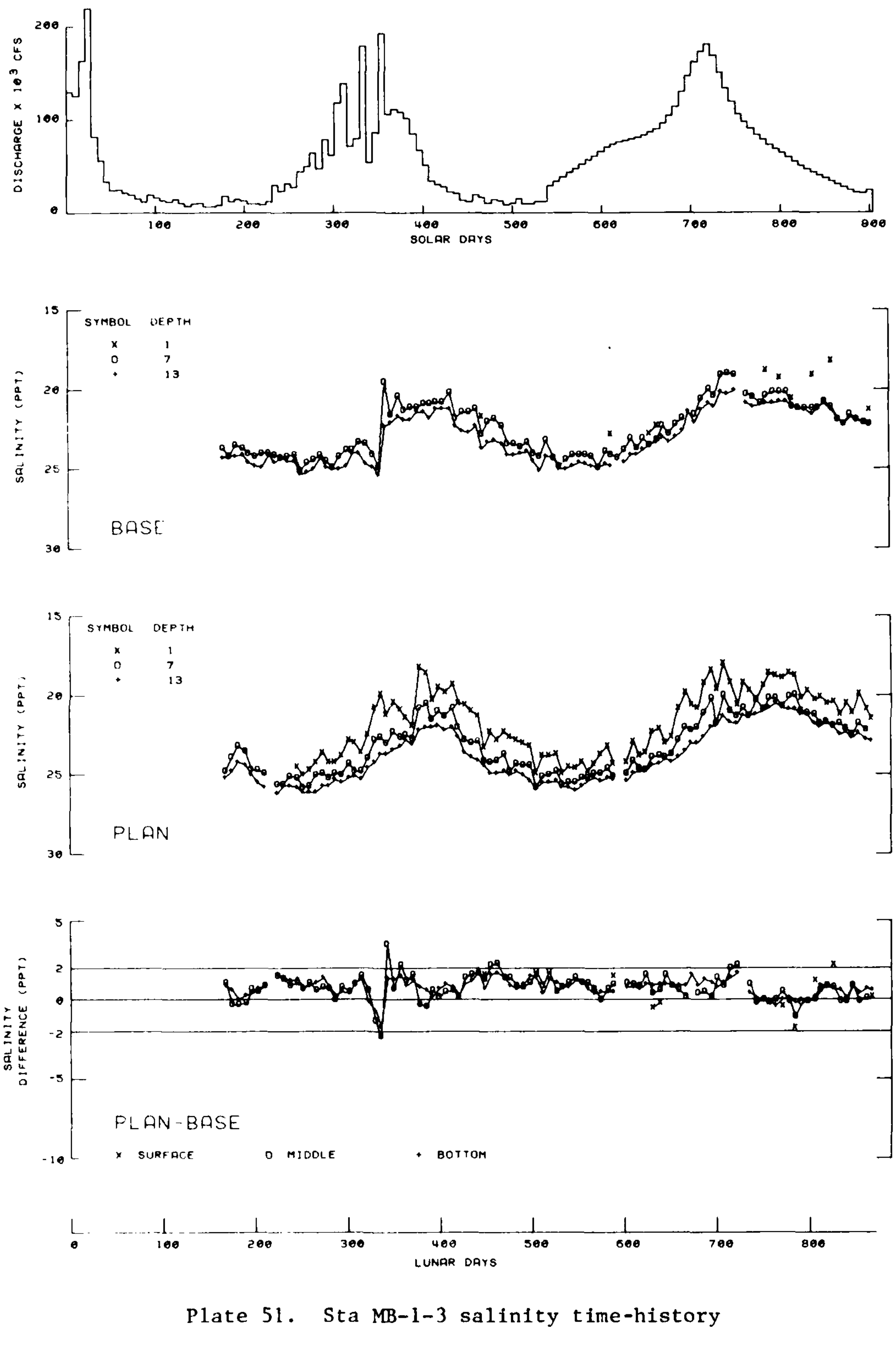


Plate 51. Sta MB-1-3 salinity time-history

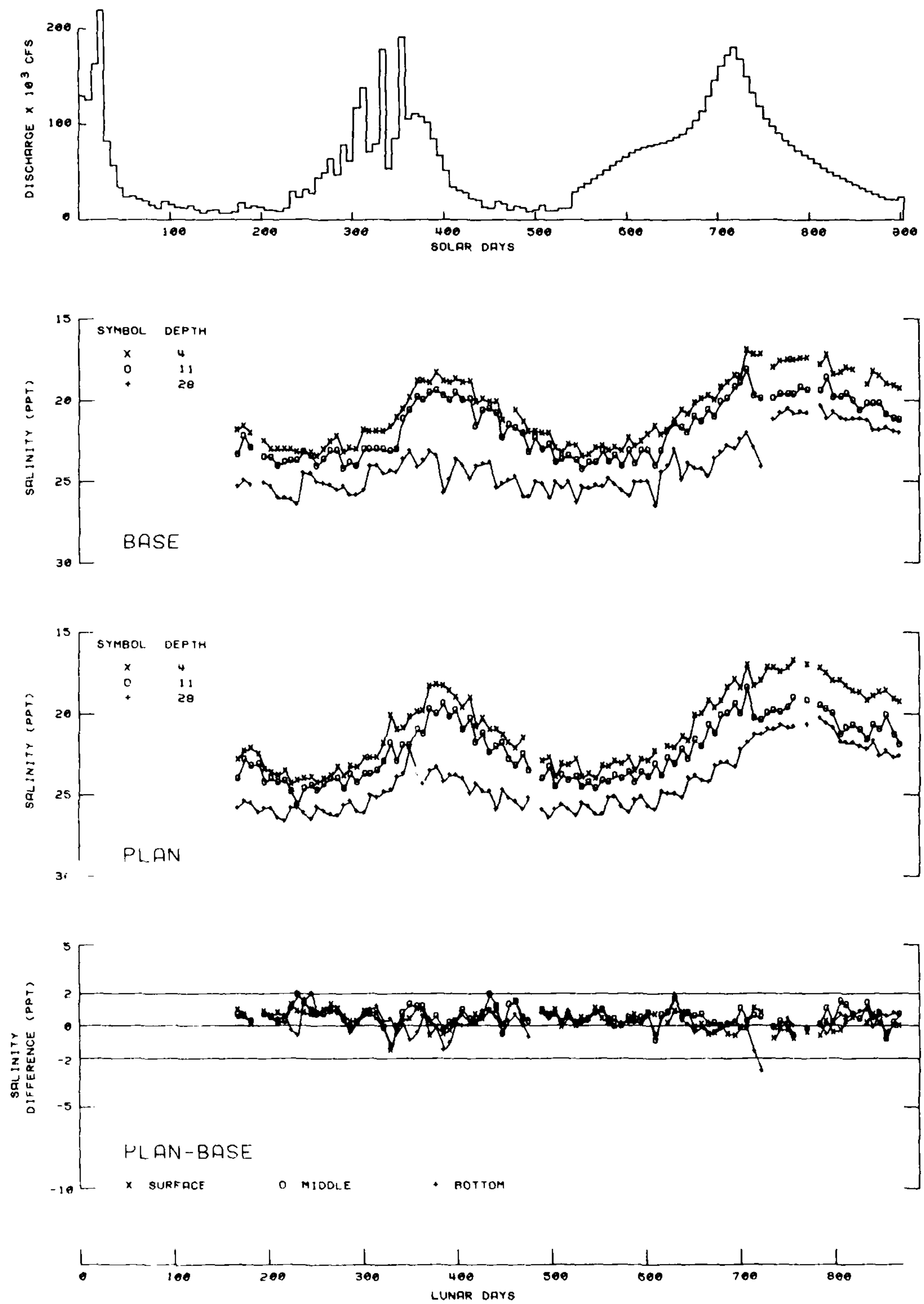


Plate 52. Sta CB-2-3 salinity time-history

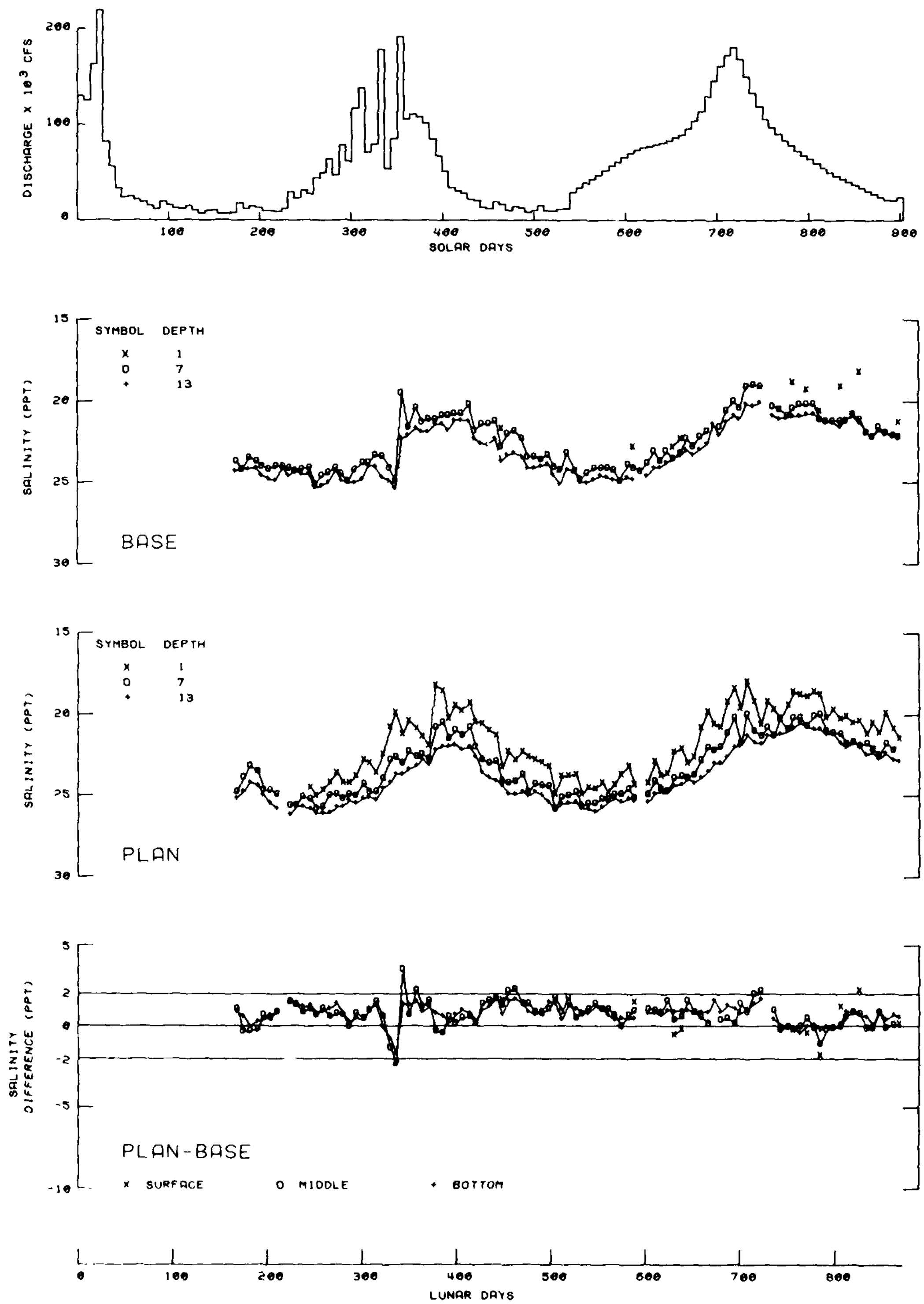


Plate 51. Sta MB-1-3 salinity time-history

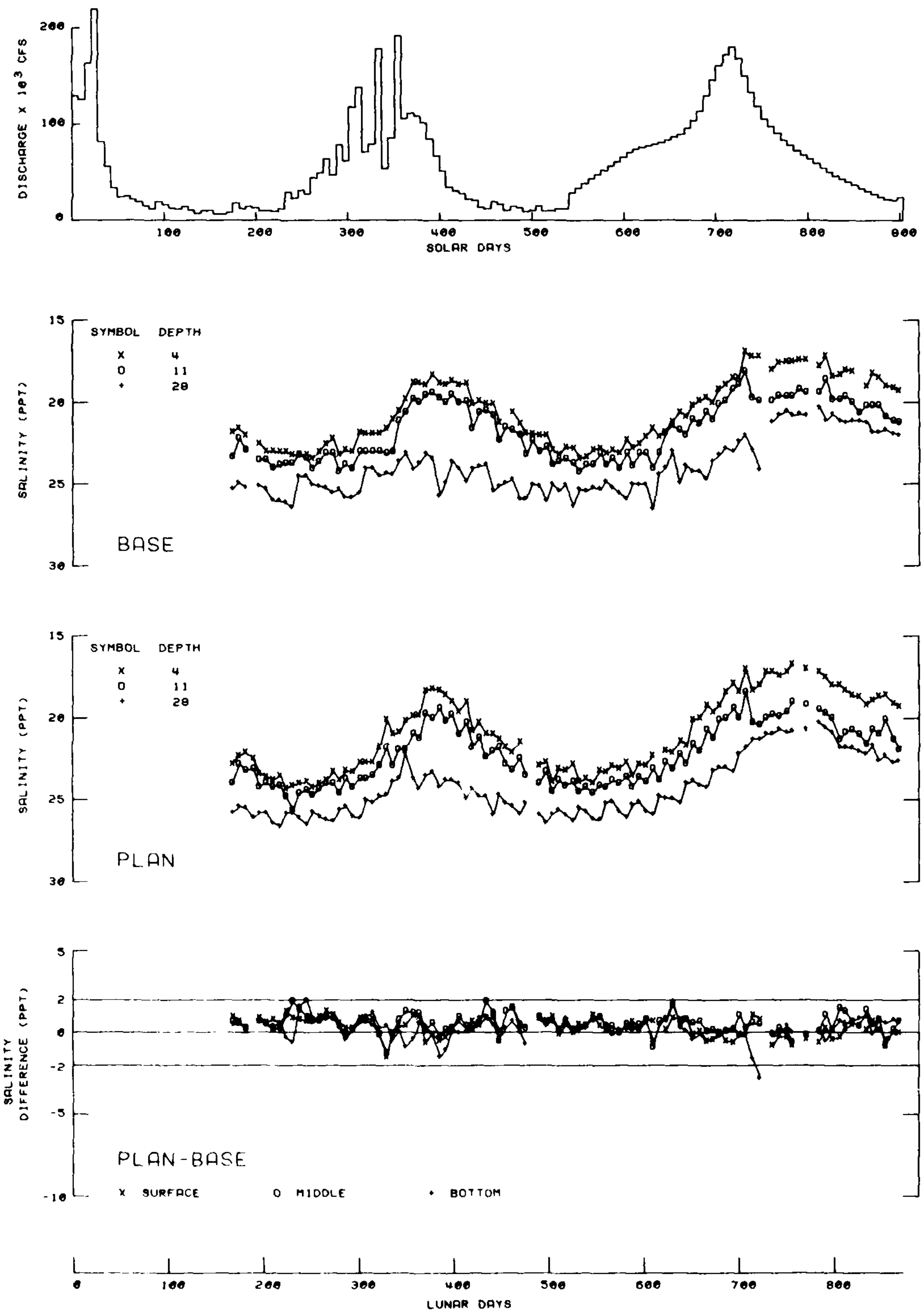


Plate 52. Sta CB-2-3 salinity time-history

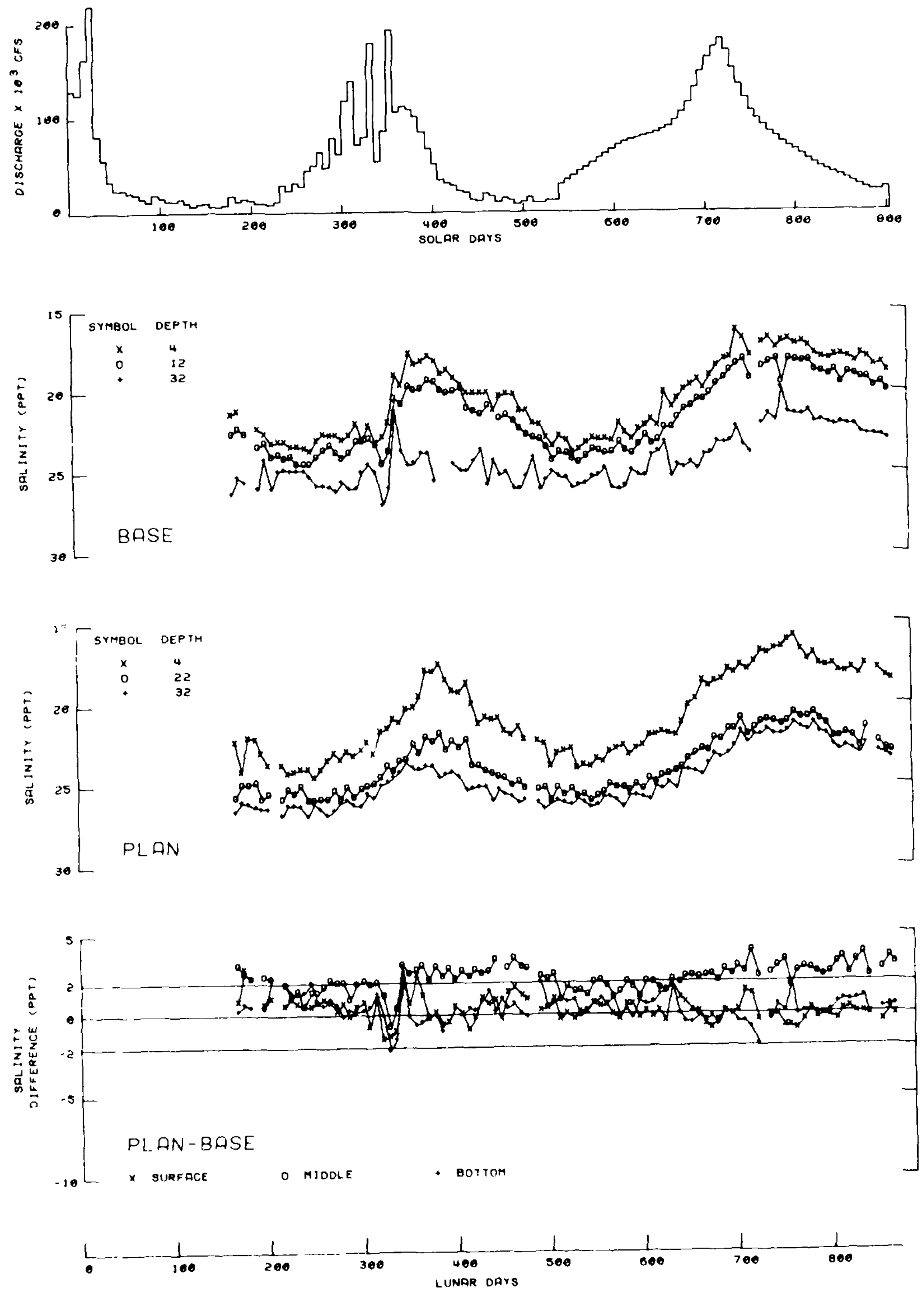


Plate 53. Sta CB-2-5 salinity time-history

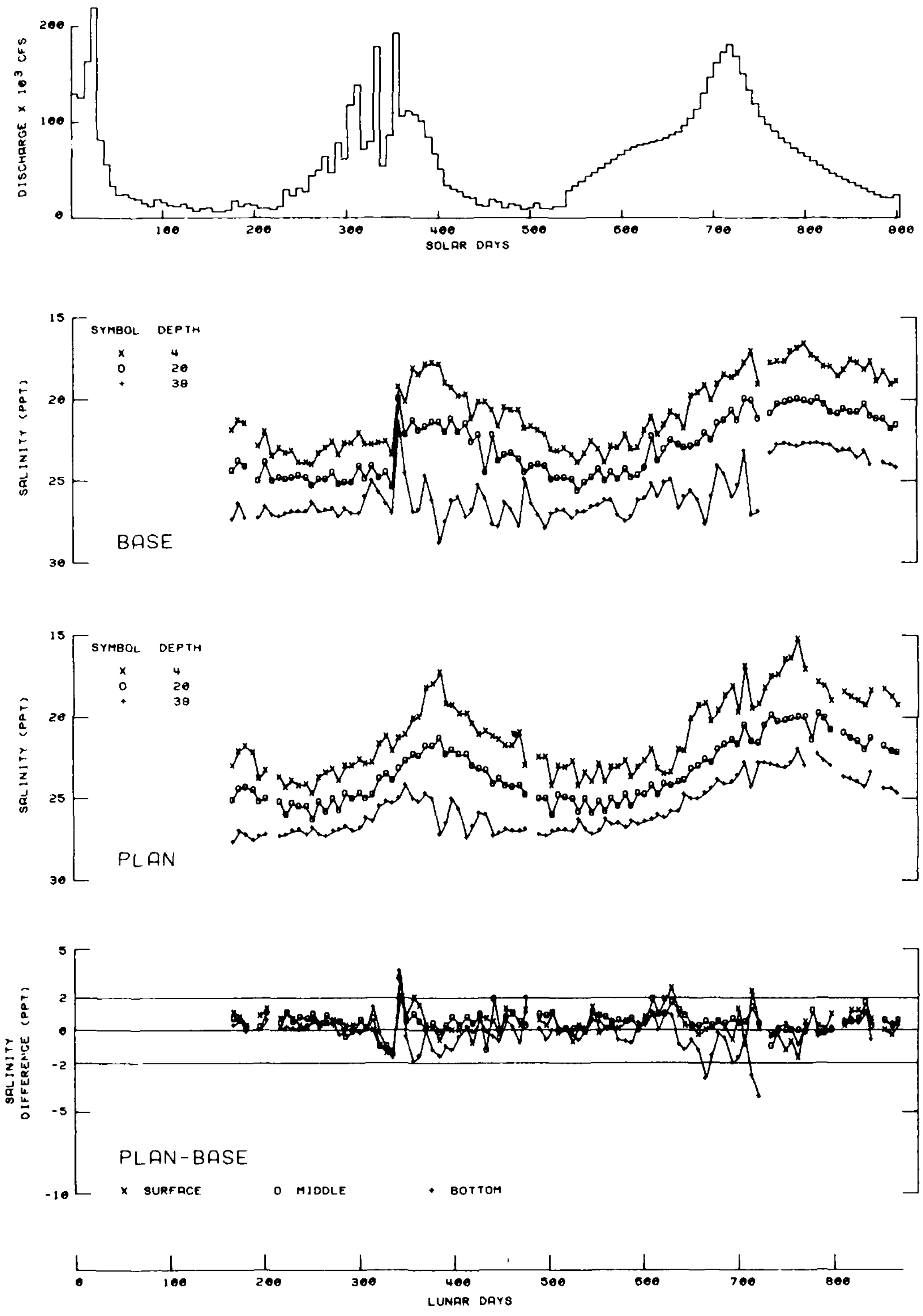


Plate 54. Sta CB-2-7 salinity time-history

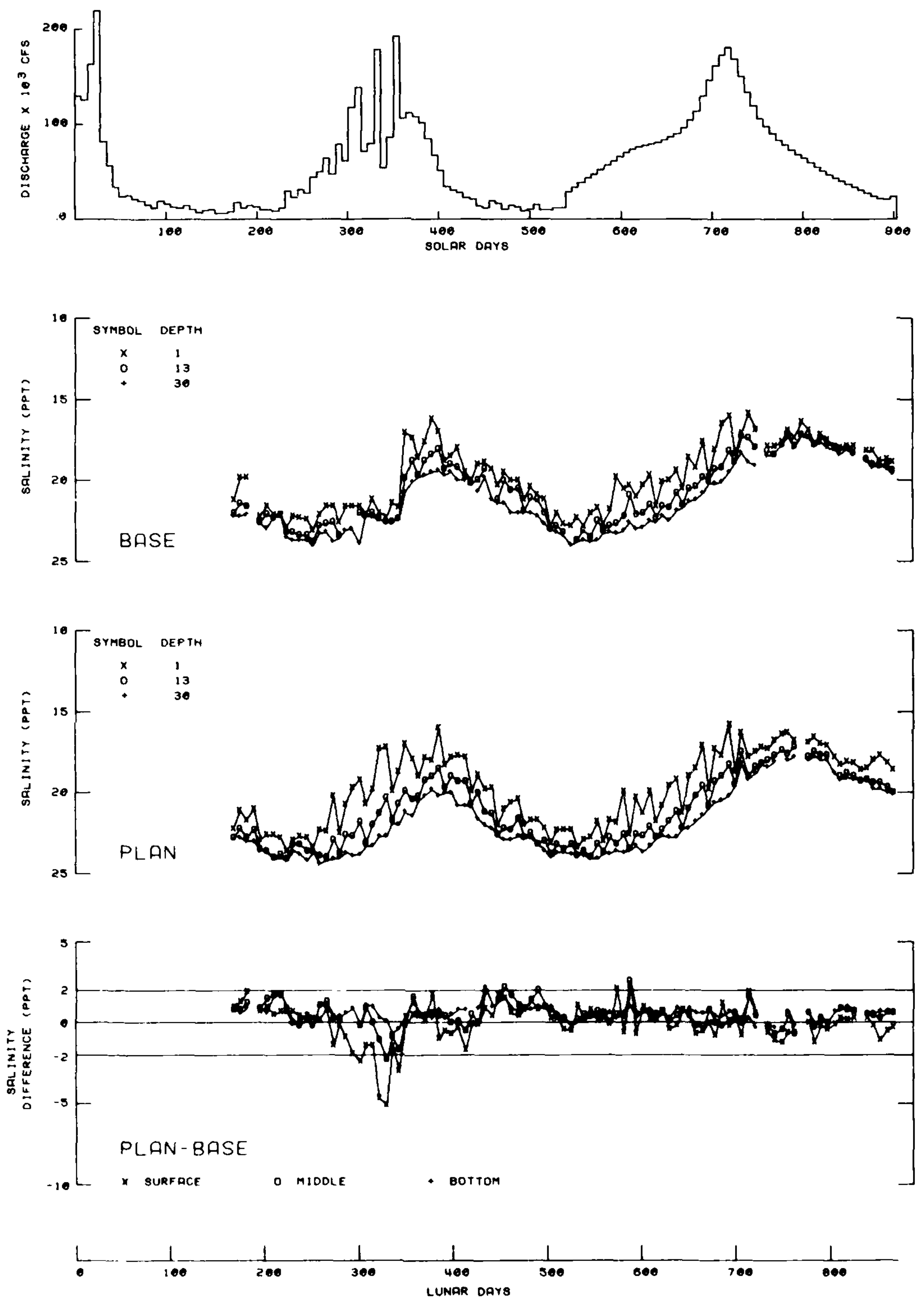


Plate 55. Sta R-1-1 salinity time-history

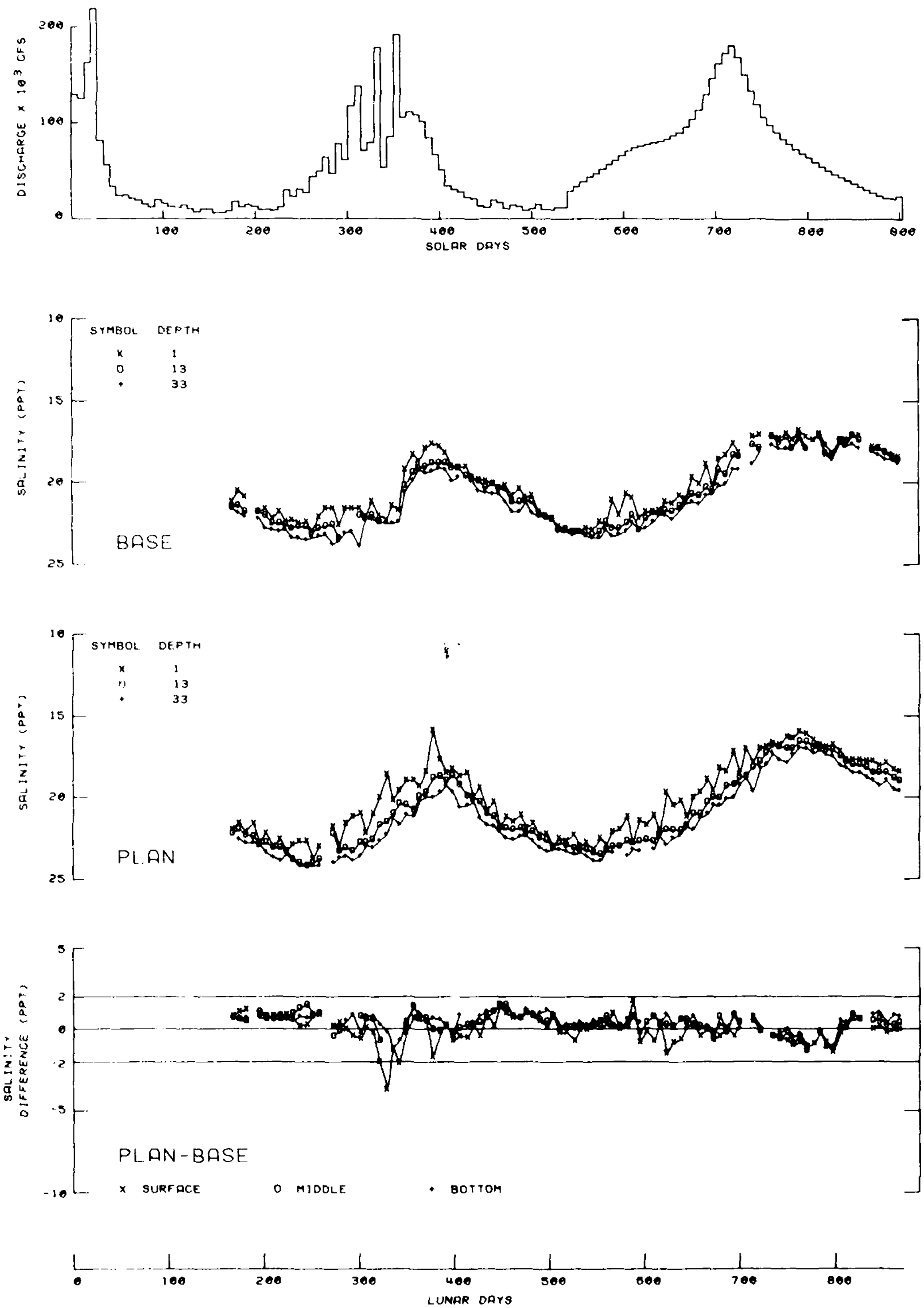


Plate 56. Sta R-1-2 salinity time-history

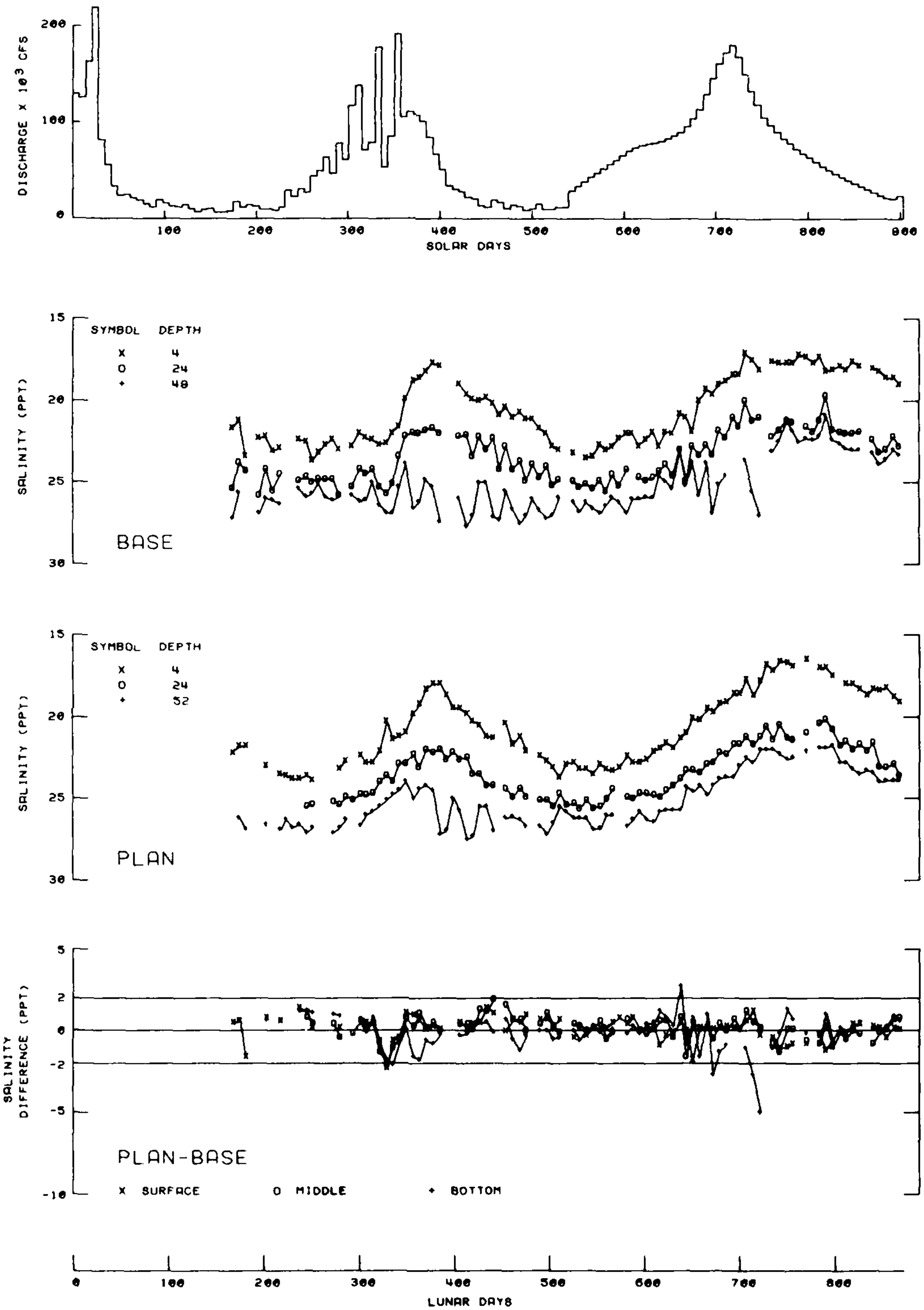


Plate 57. Sta RSC-1 salinity time-history

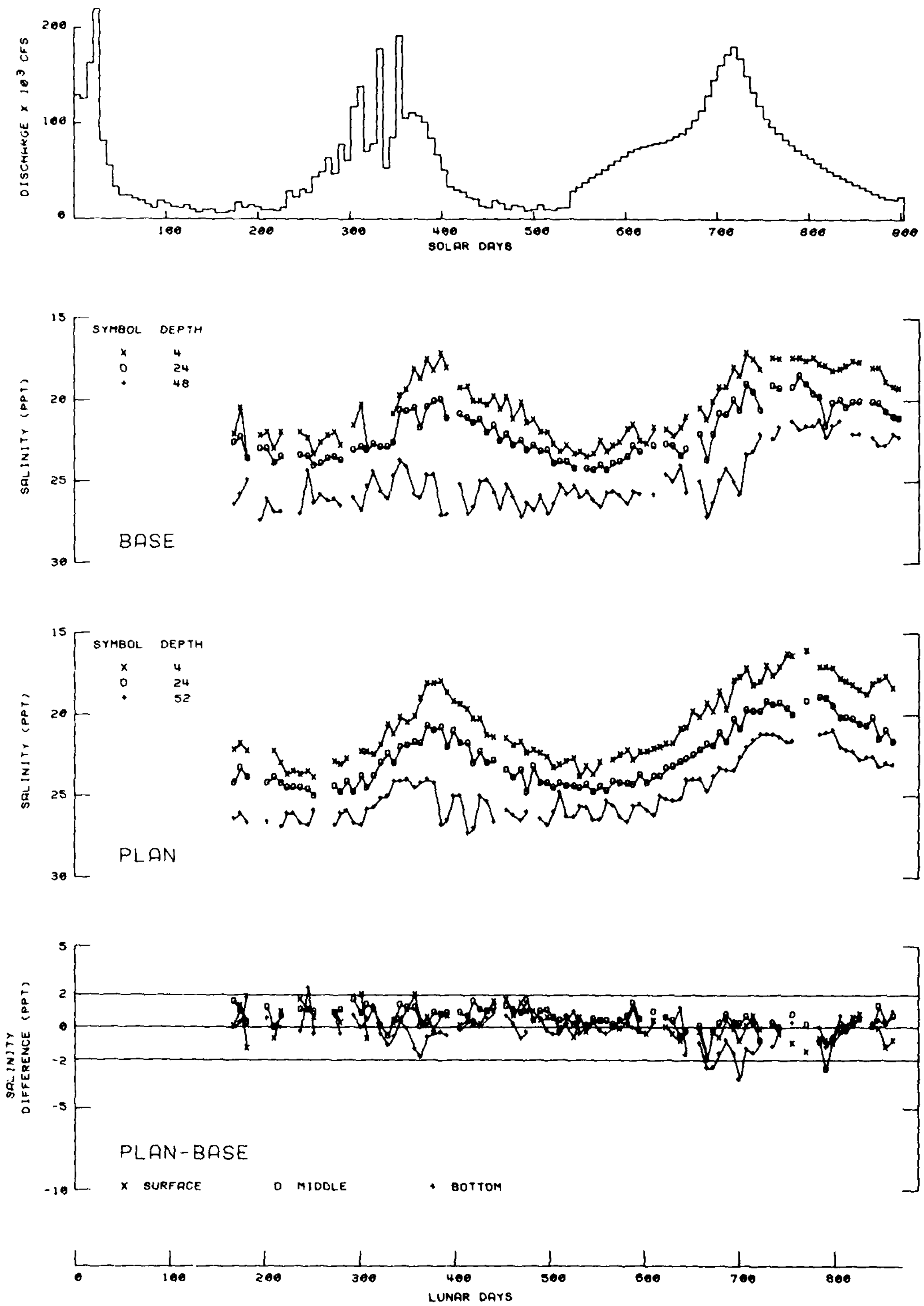


Plate 58. Sta RSC-2 salinity time-history

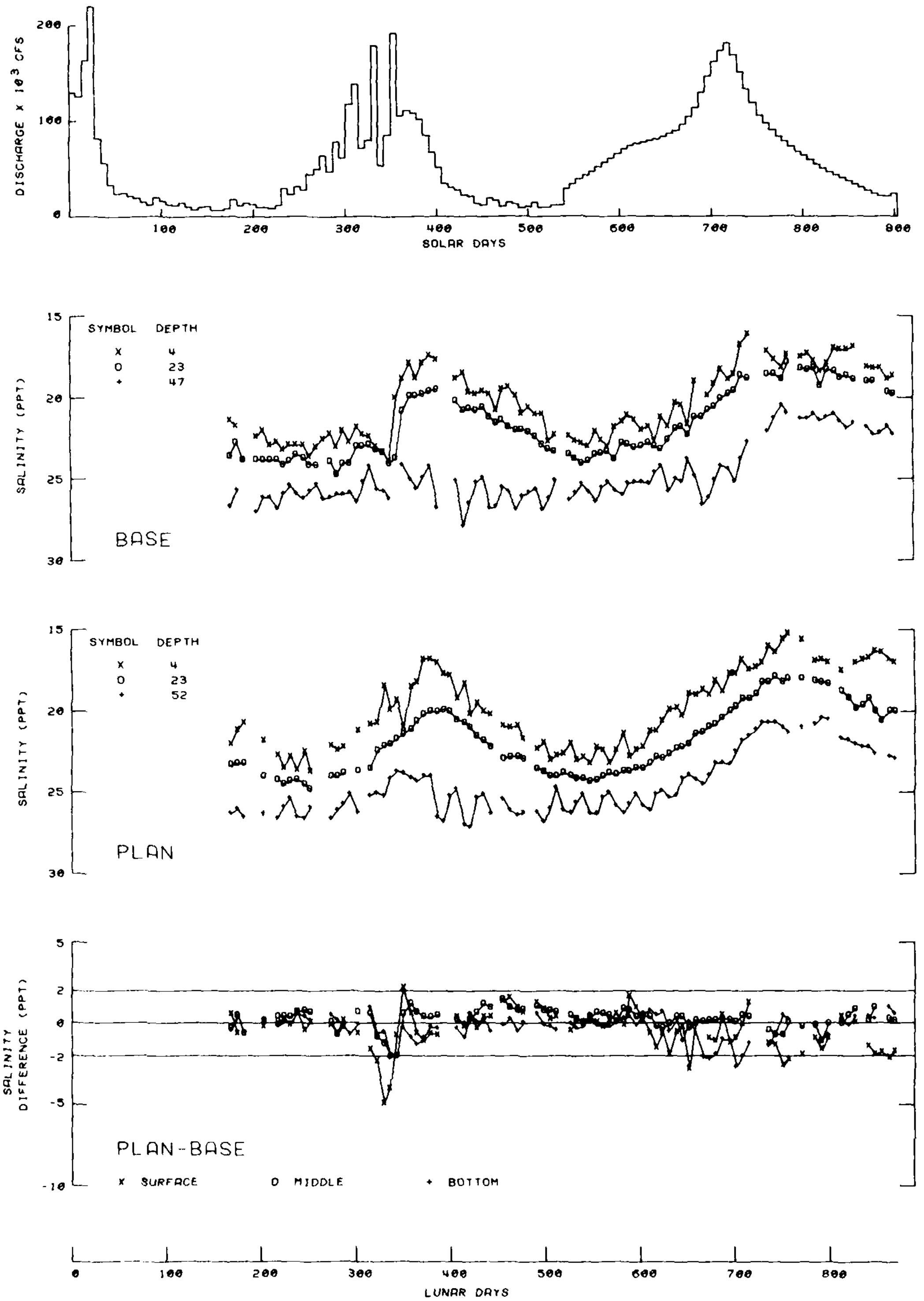


Plate 59. Sta RSC-3 salinity time-history

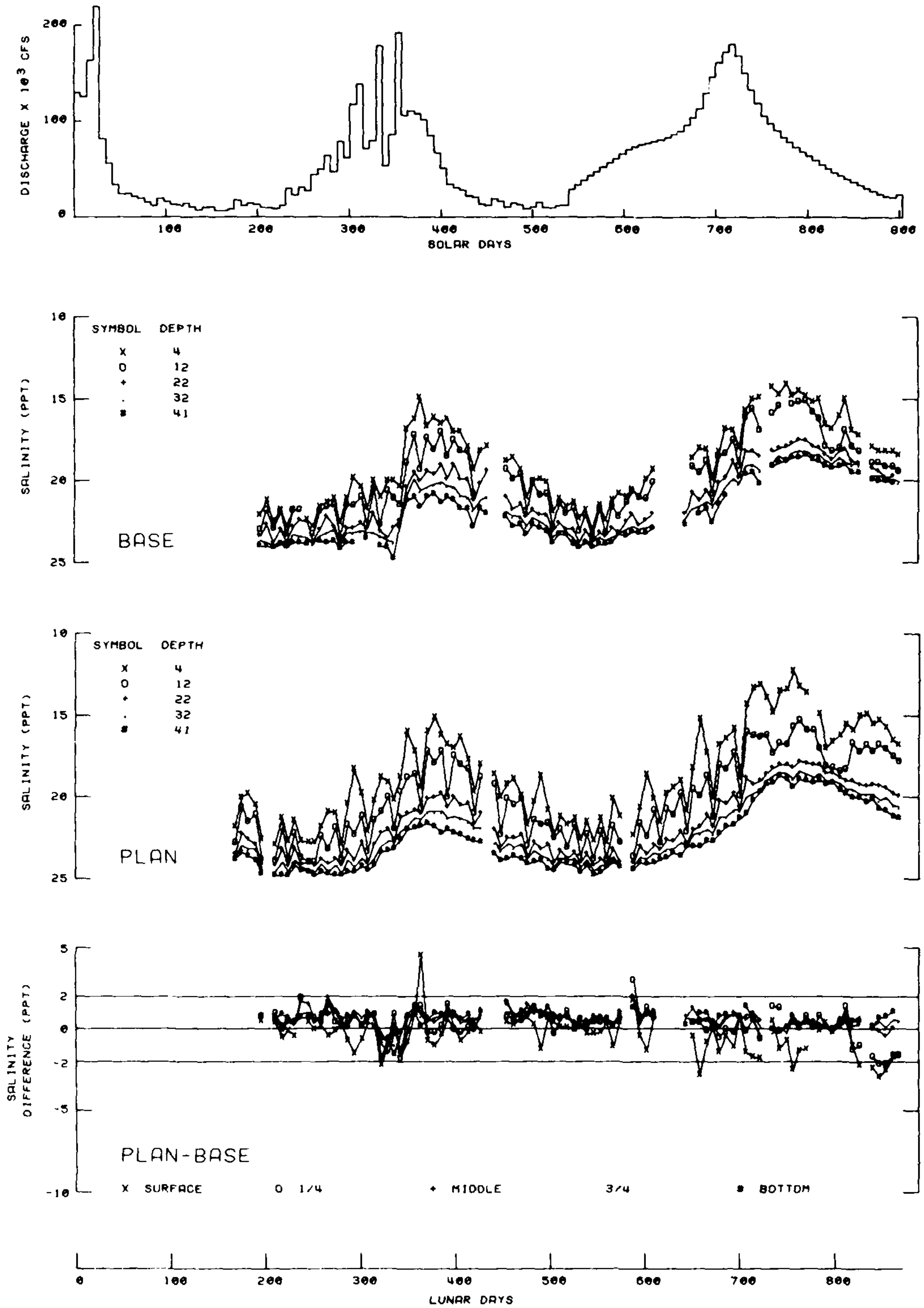


Plate 60. Sta CB-3-4 salinity time-history

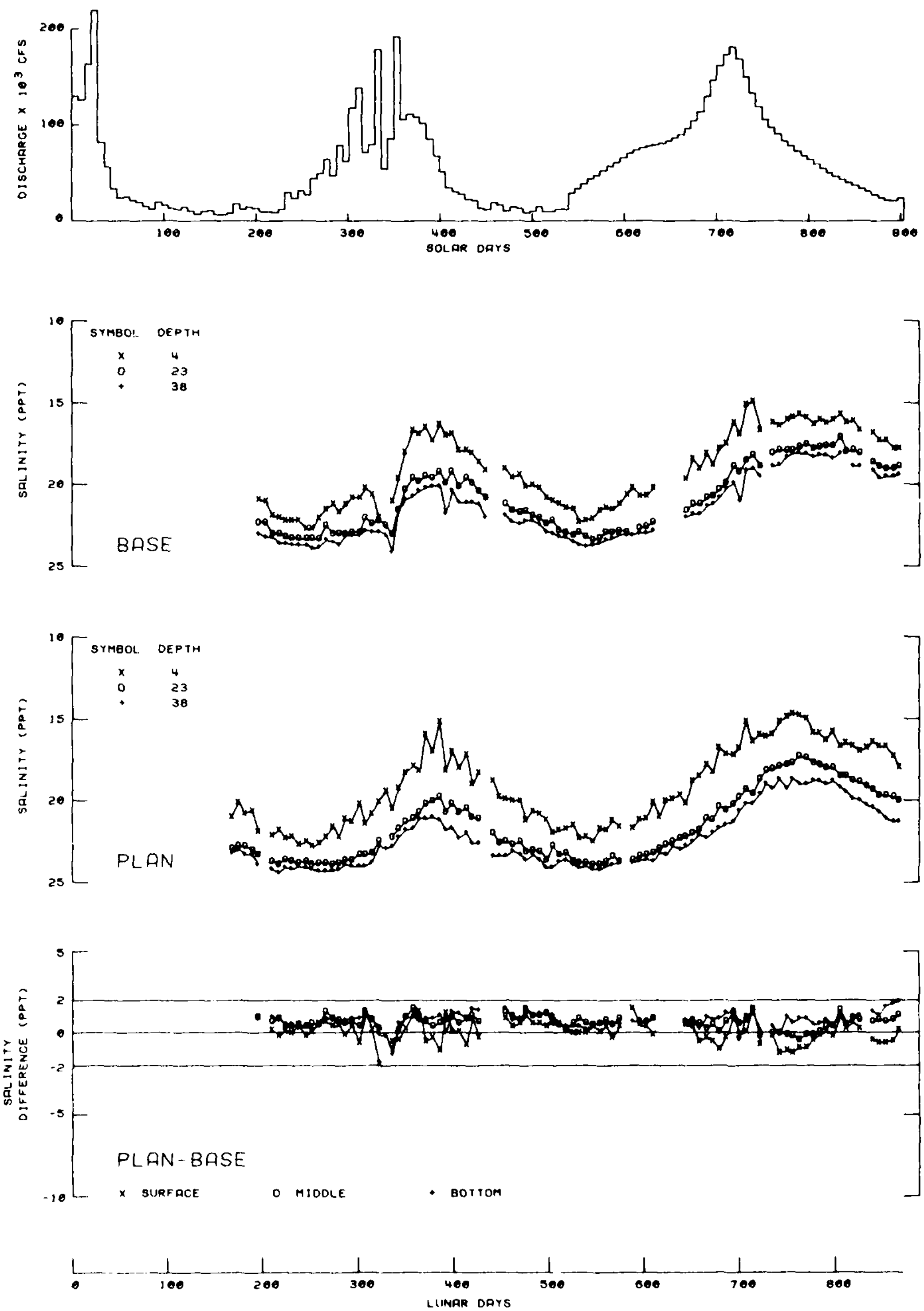


Plate 61. Sta CB-3-6 salinity time-history

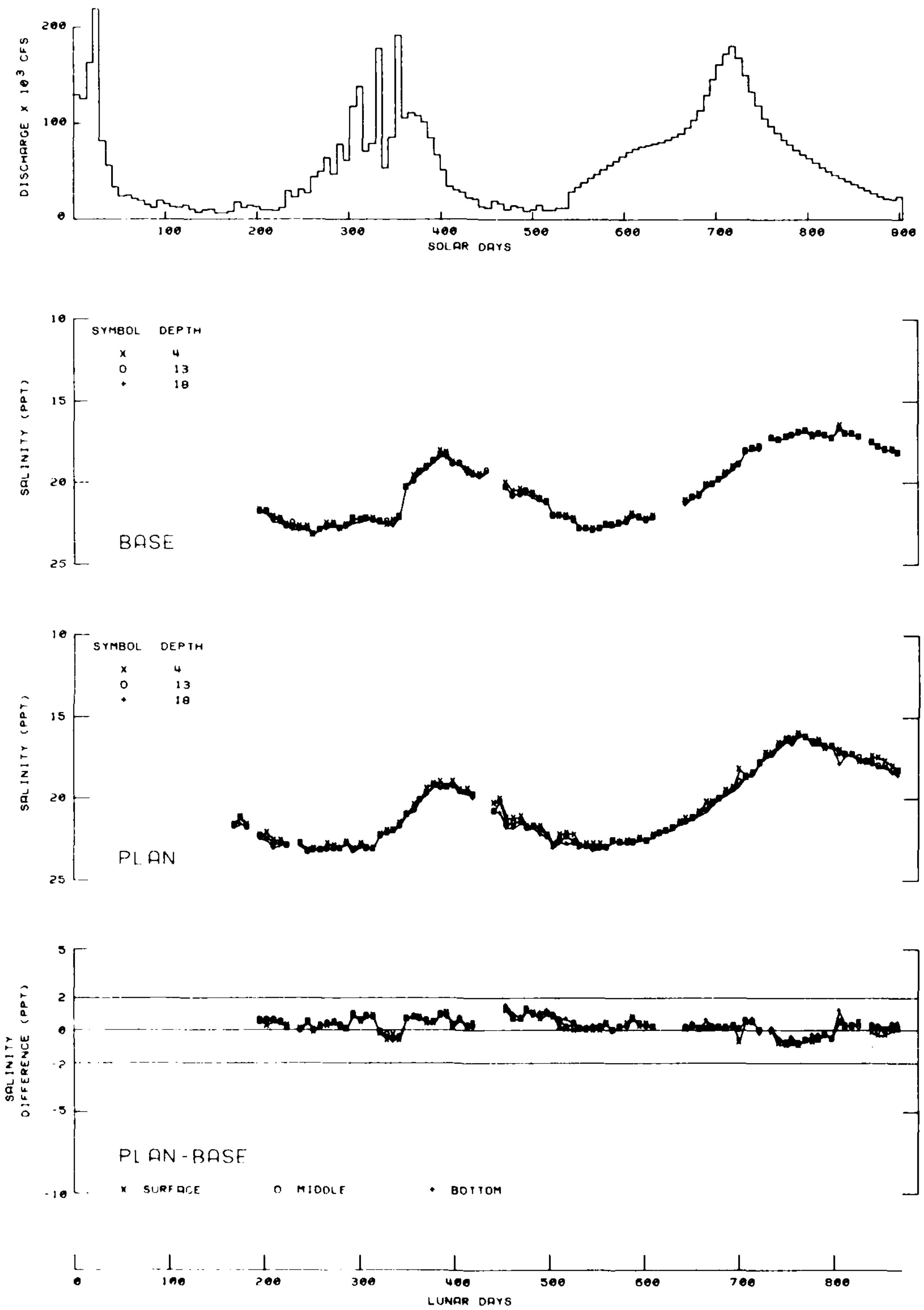


Plate 62. Sta CB-3-8 salinity time-history

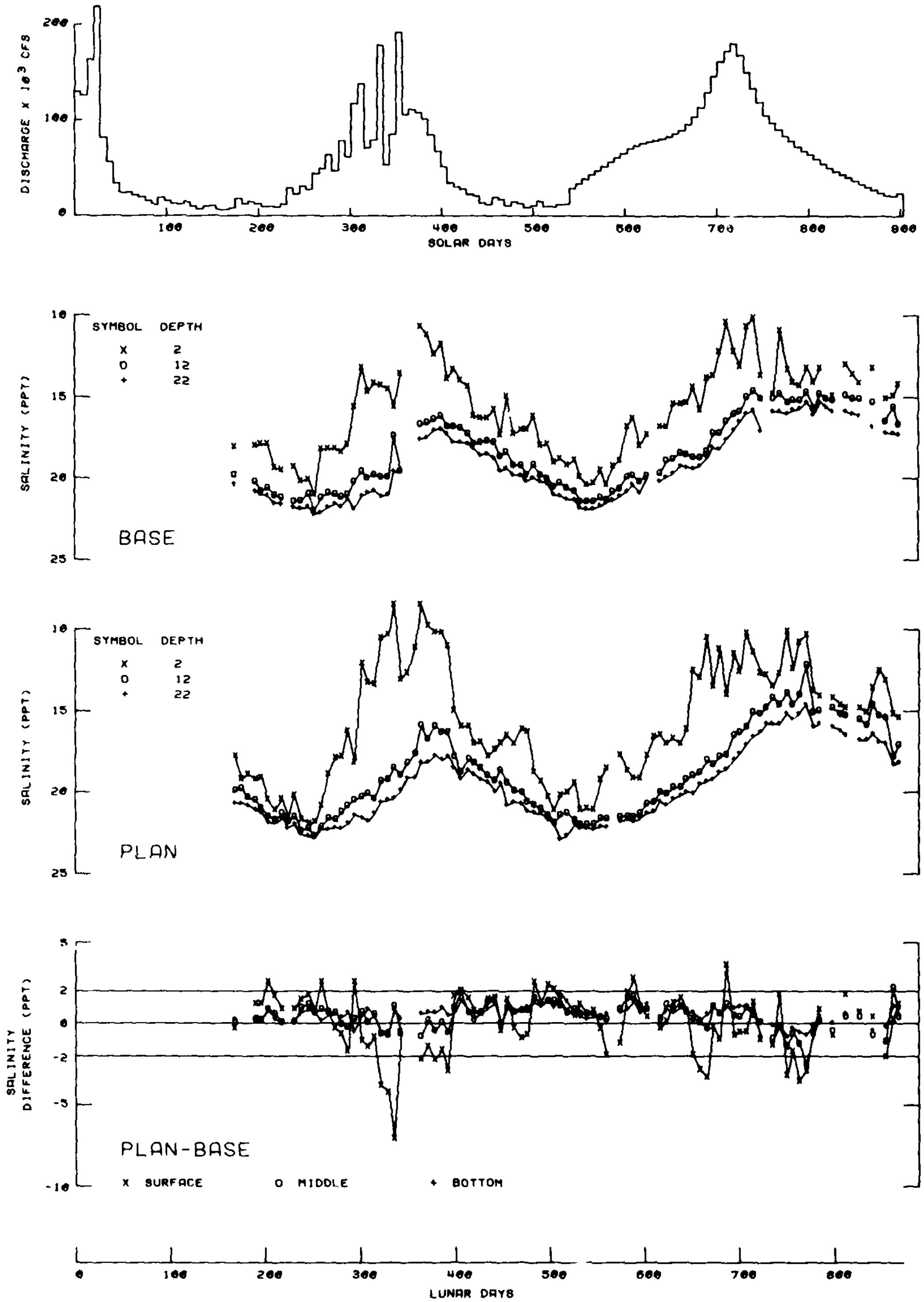


Plate 63. Sta PO-I-1 salinity time-history

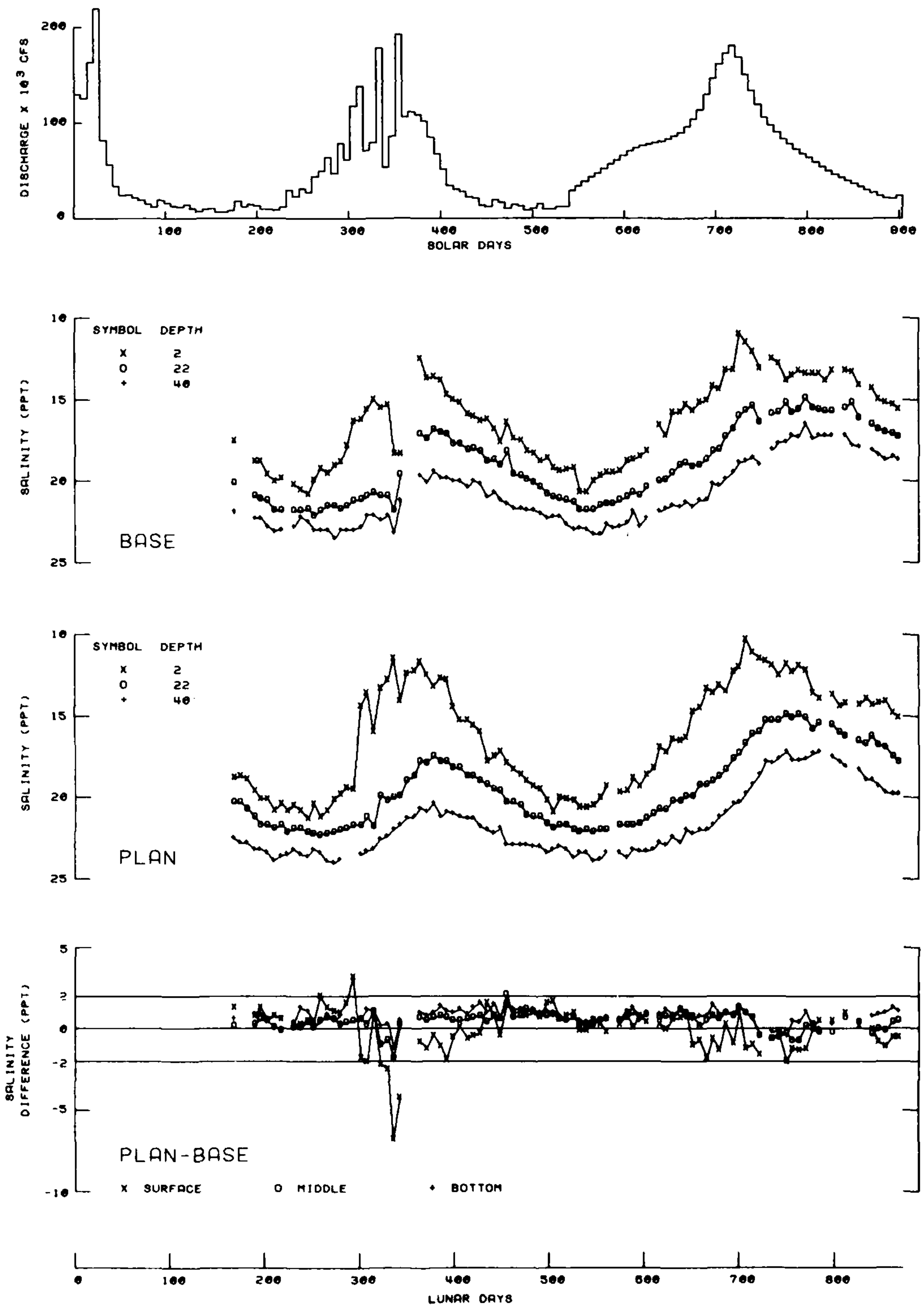


Plate 64. Sta PO-1-3 salinity time-history

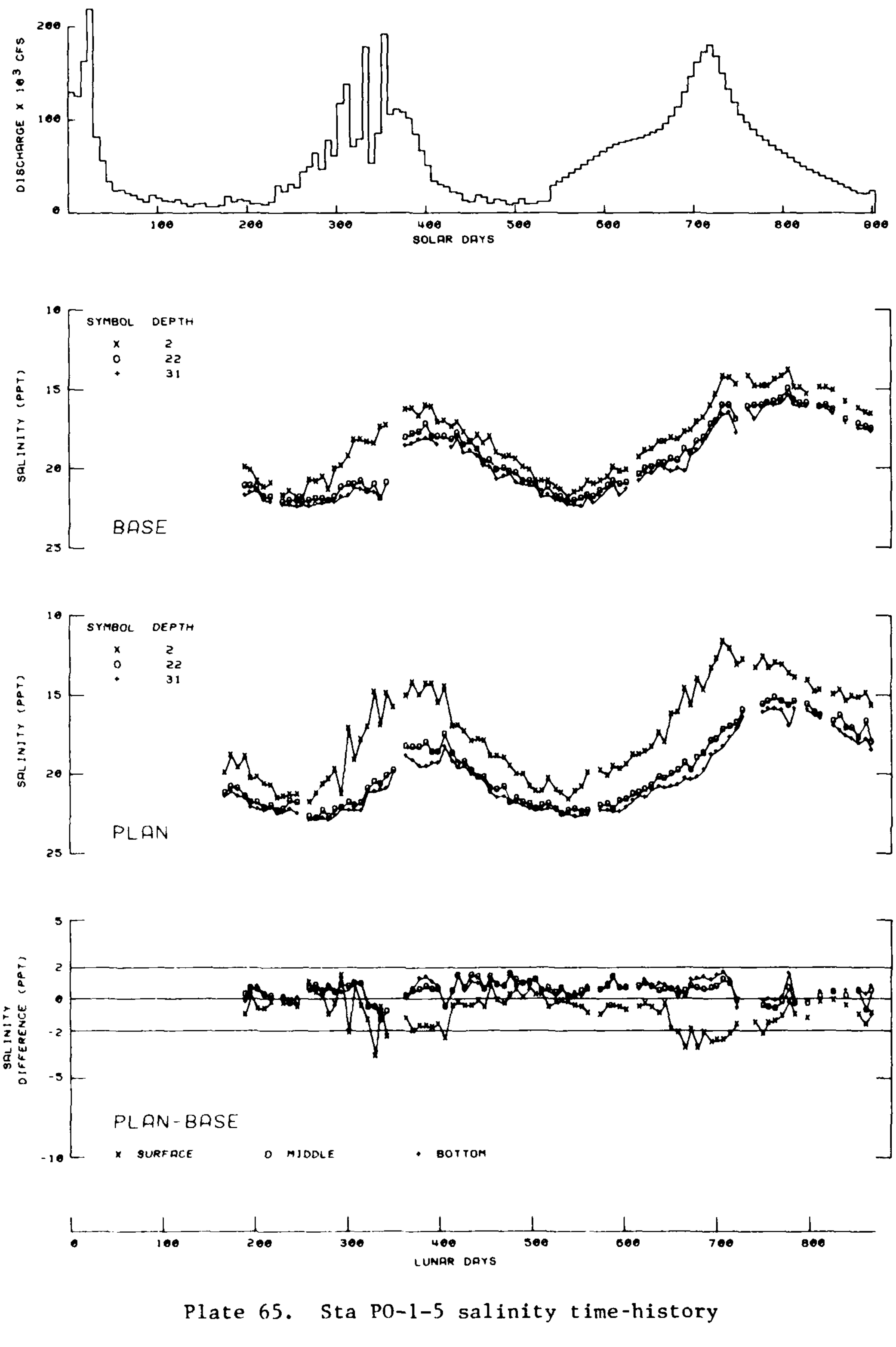


Plate 65. Sta PO-1-5 salinity time-history

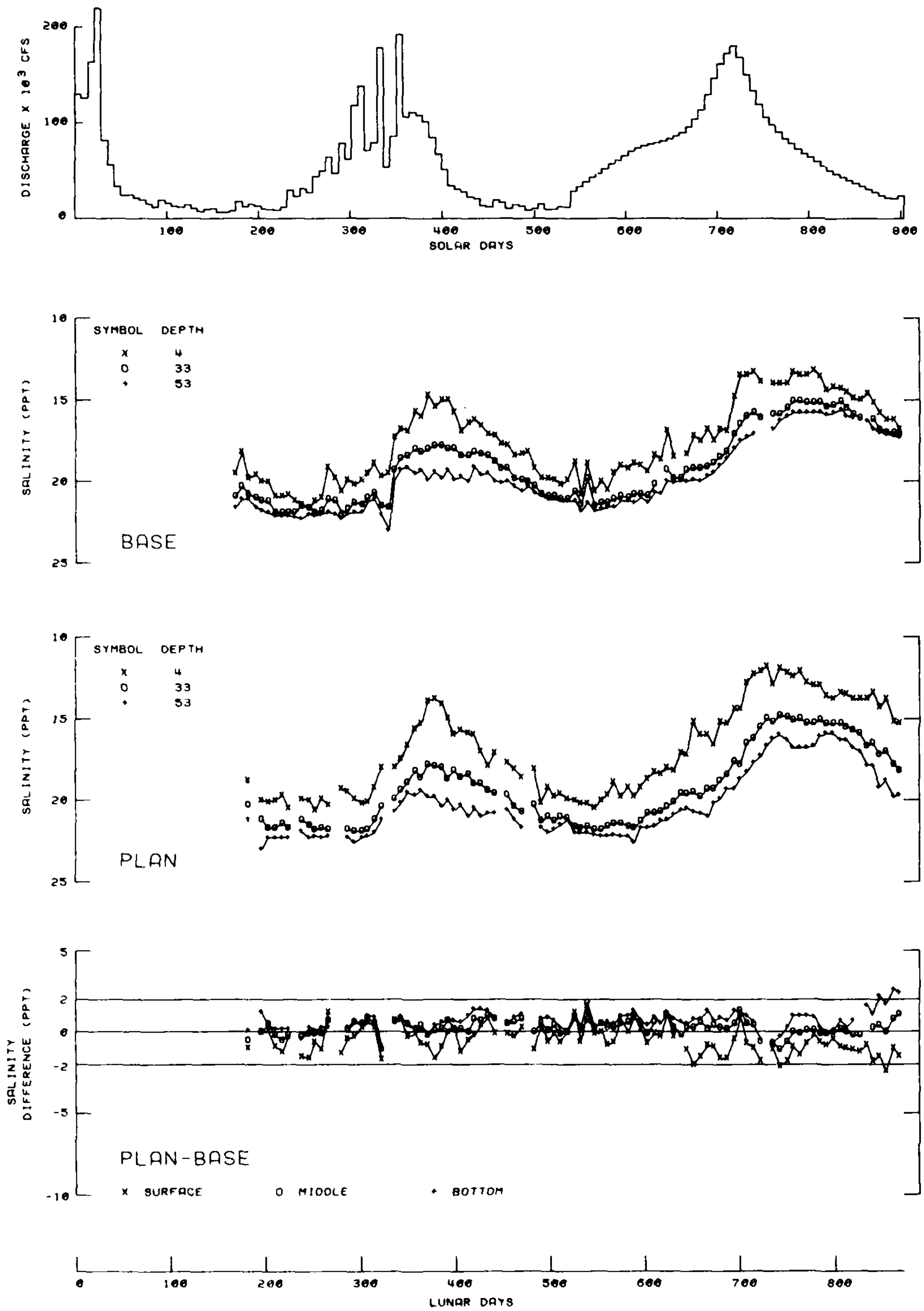


Plate 66. Sta CB-4-3 salinity time-history

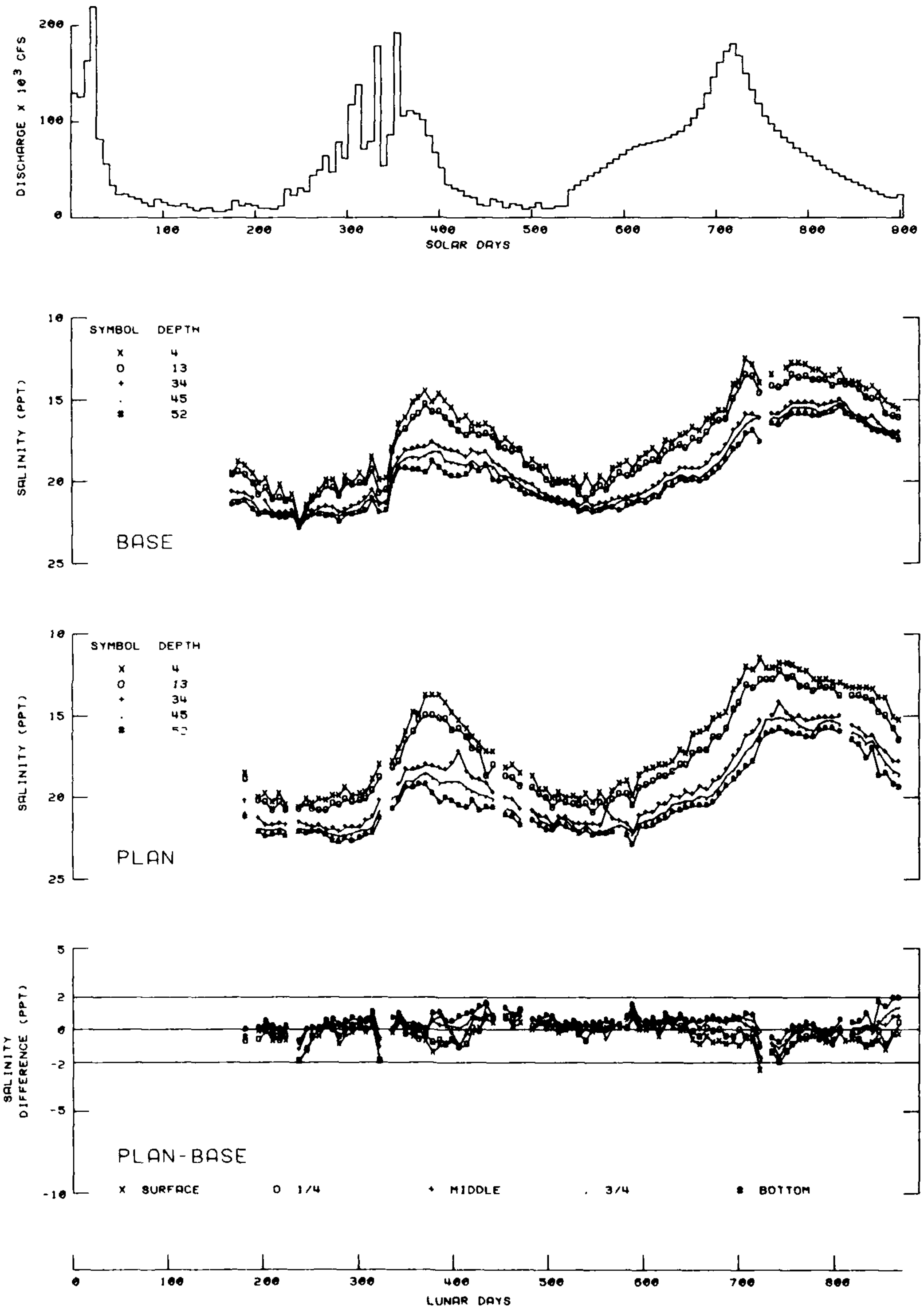


Plate 67. Sta CB-4-4 salinity time-history

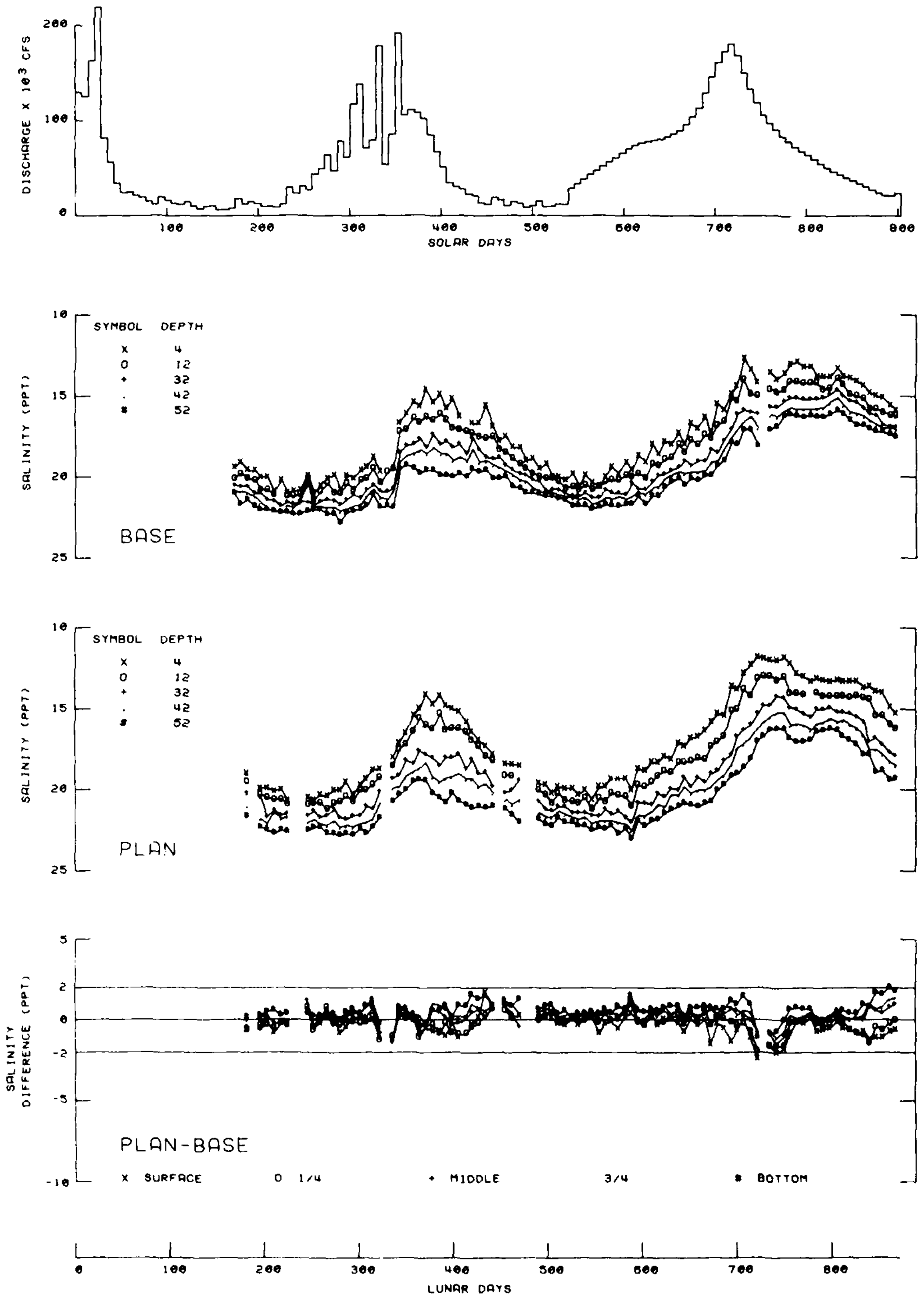


Plate 68. Sta CB-4-5 salinity time-history

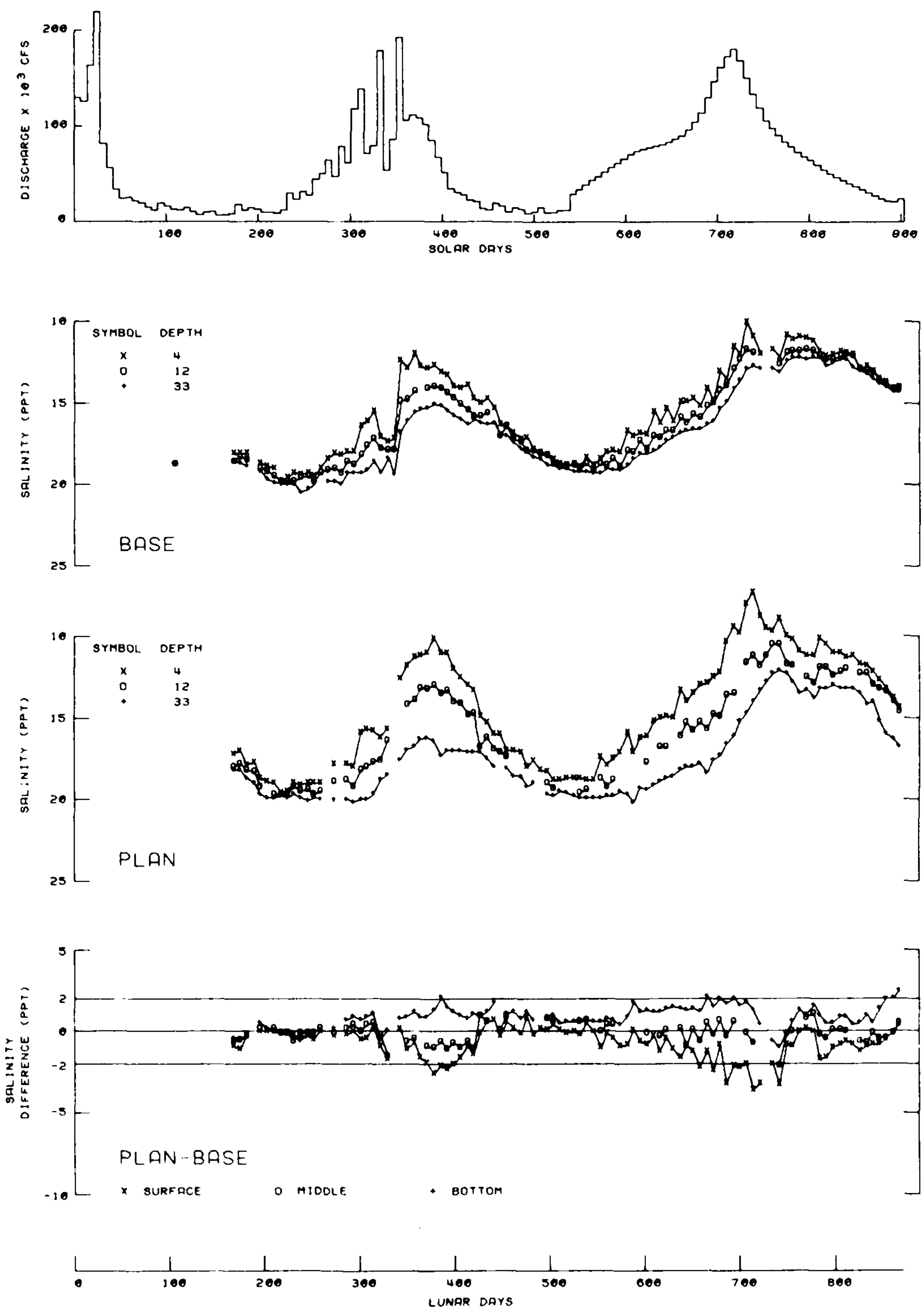


Plate 69. Sta CB-5-2 salinity time-history

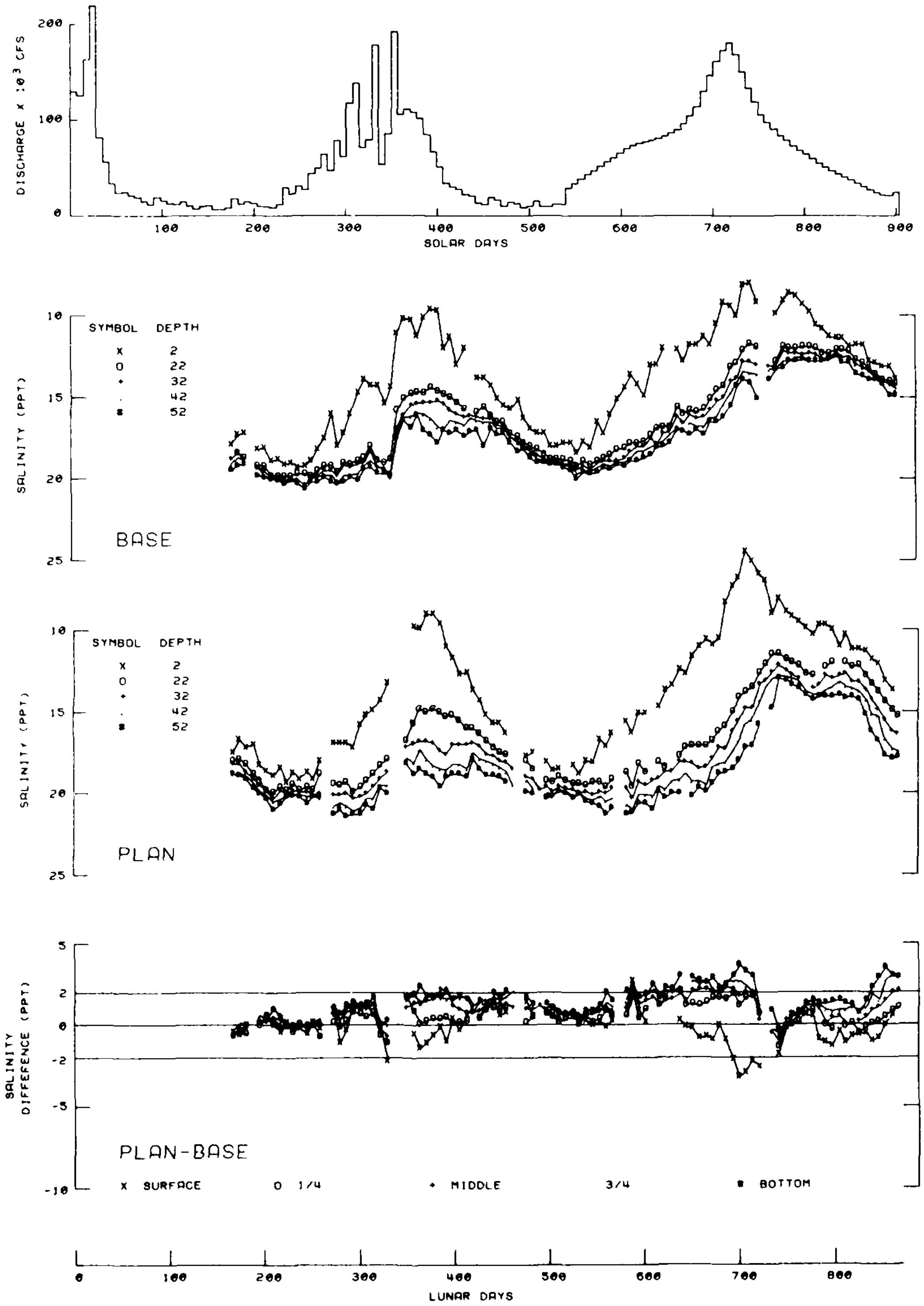


Plate 70. Sta CB-5-4 salinity time-history

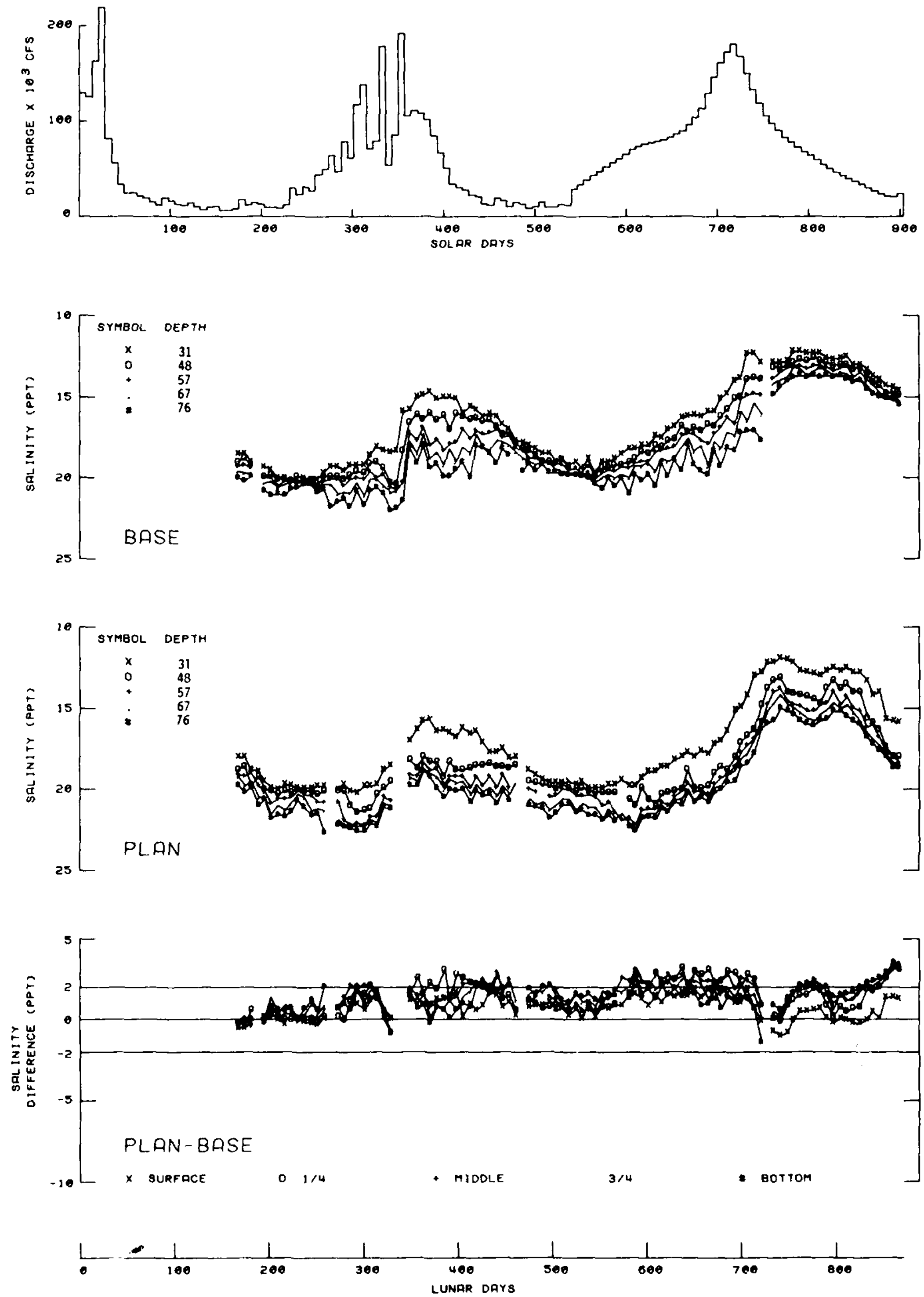


Plate 71. Sta CB-5-5 salinity time-history

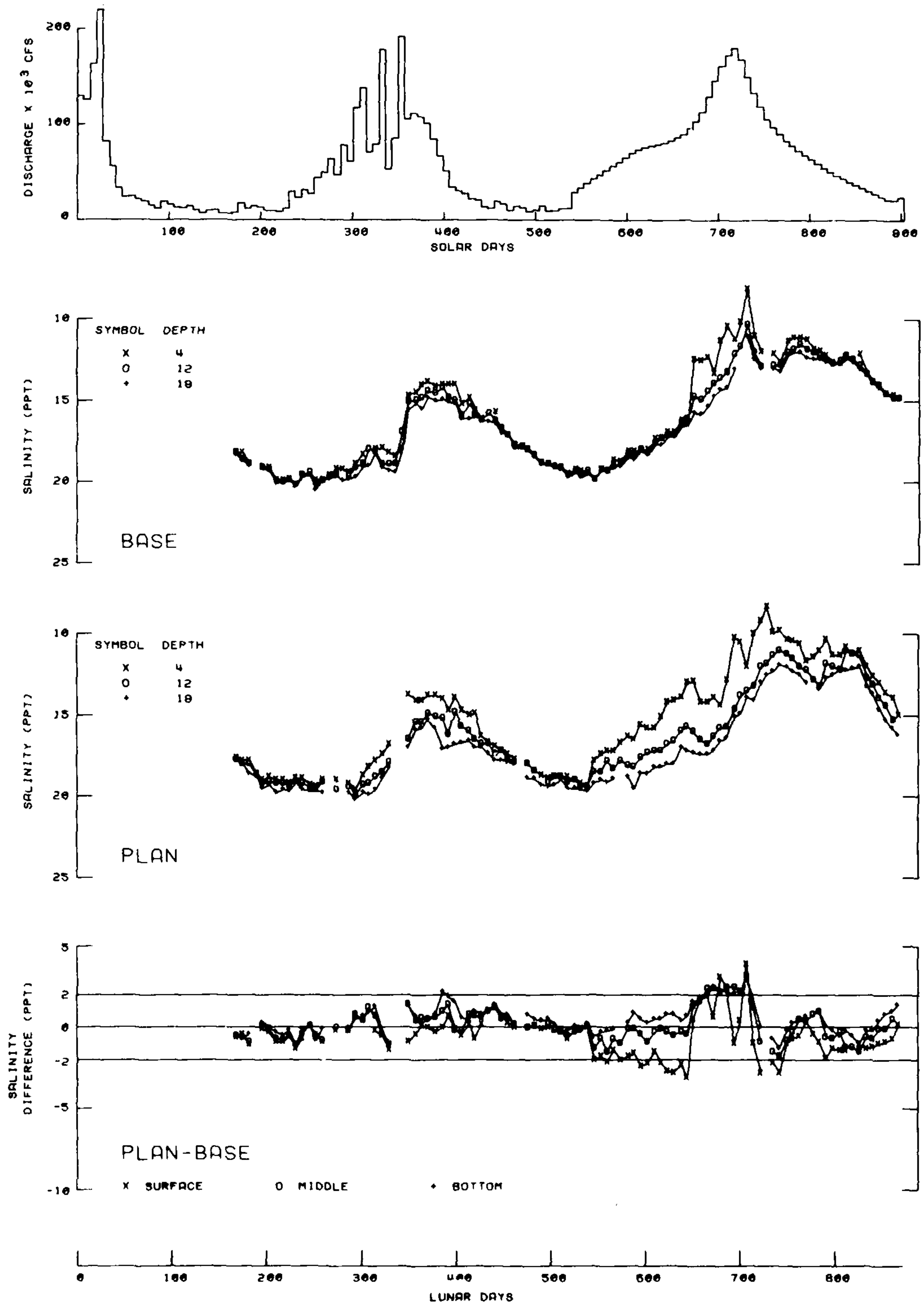


Plate 72. Sta CB-5-6 salinity time-history

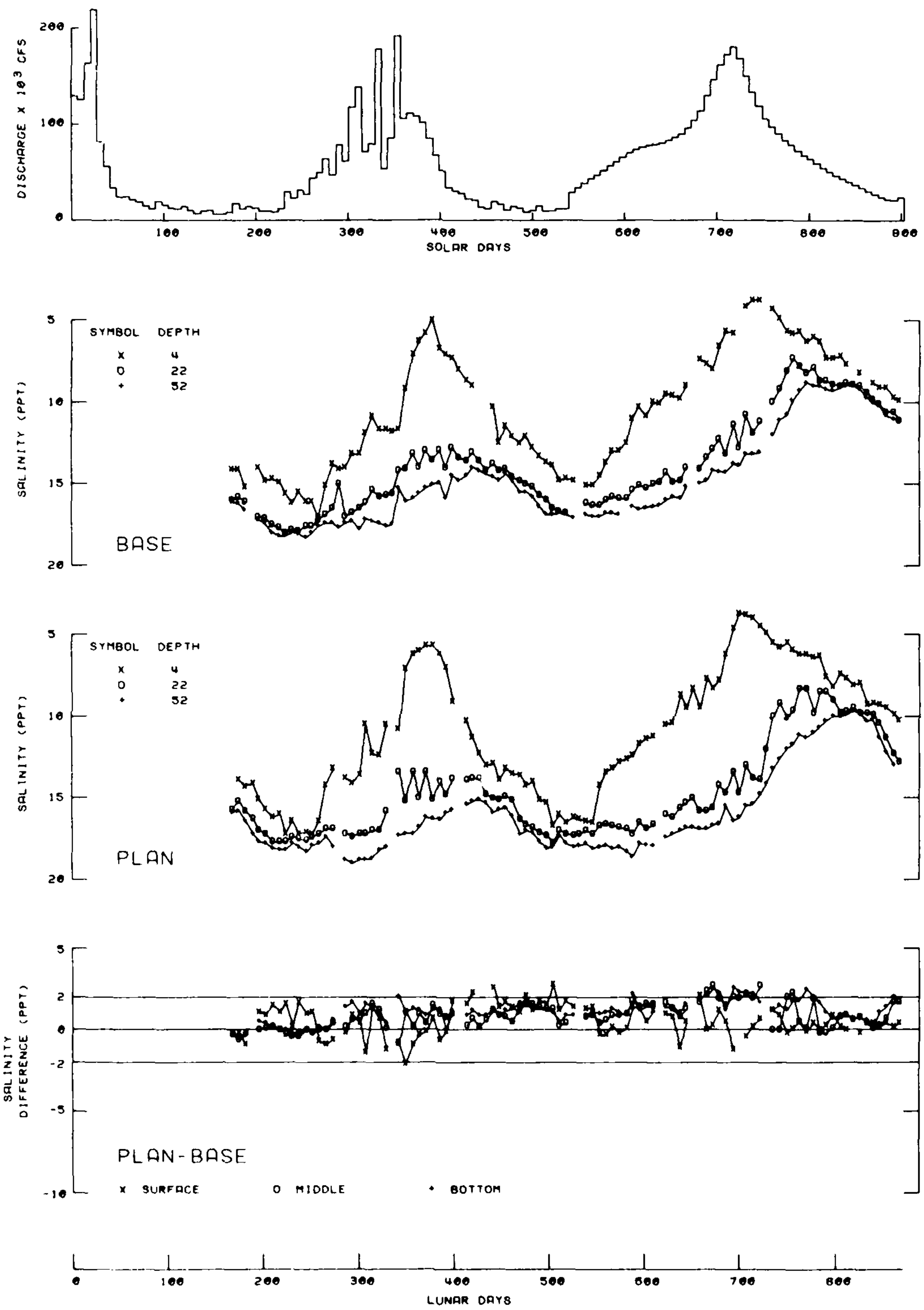


Plate 73. Sta CH-1-1 salinity time-history

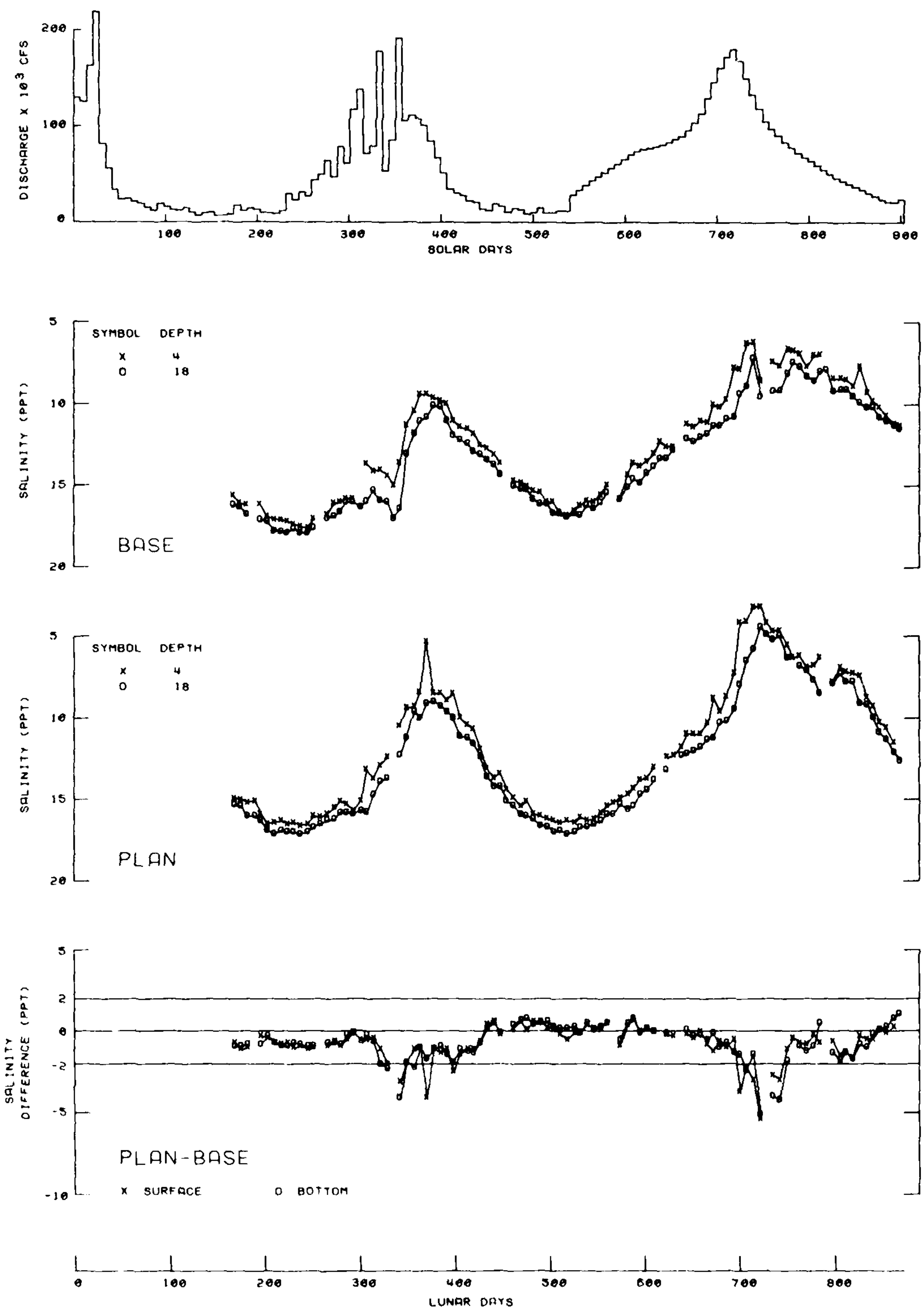


Plate 74. Sta MA-1 salinity time-history

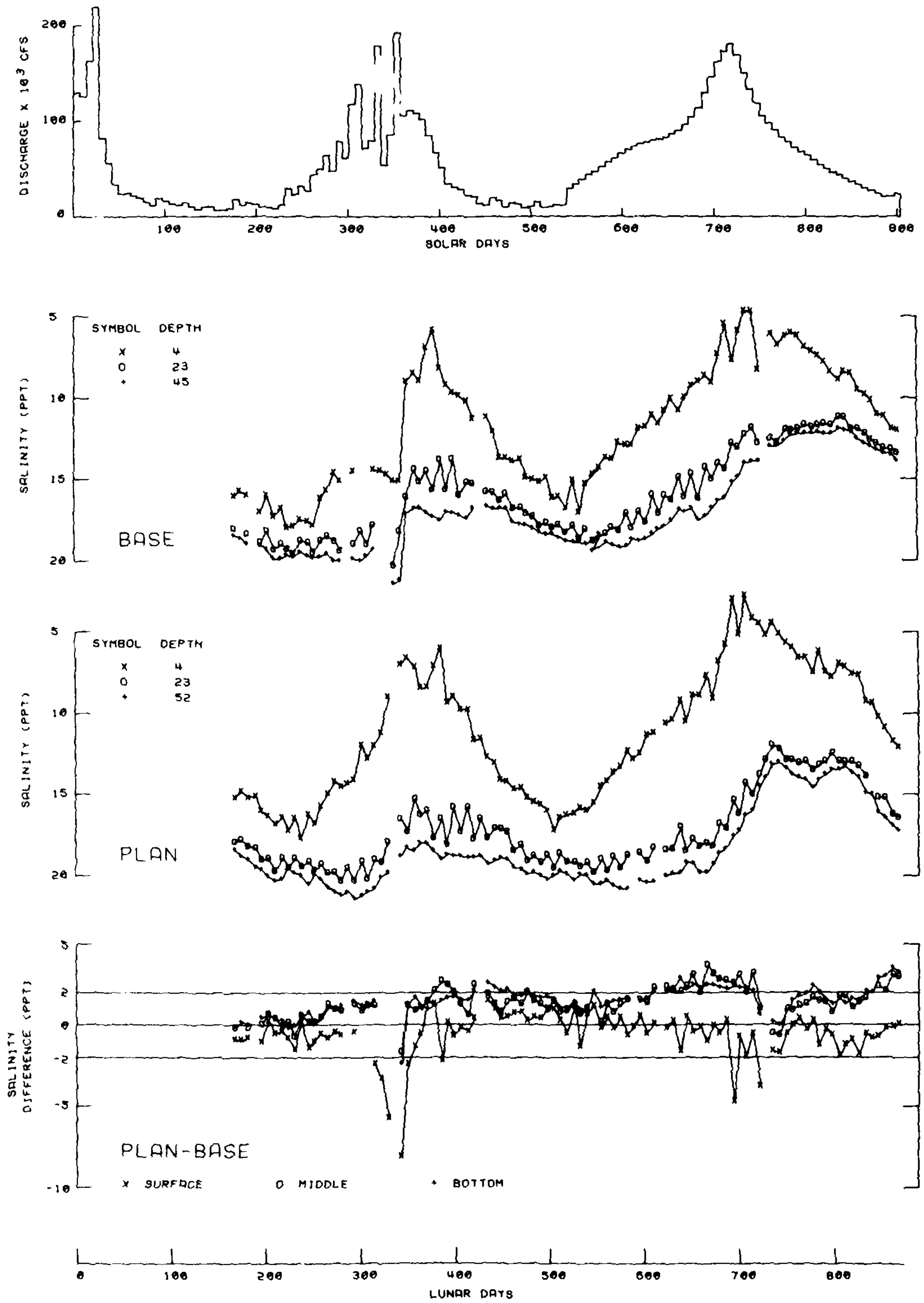


Plate 75. Sta CC-1 salinity time-history

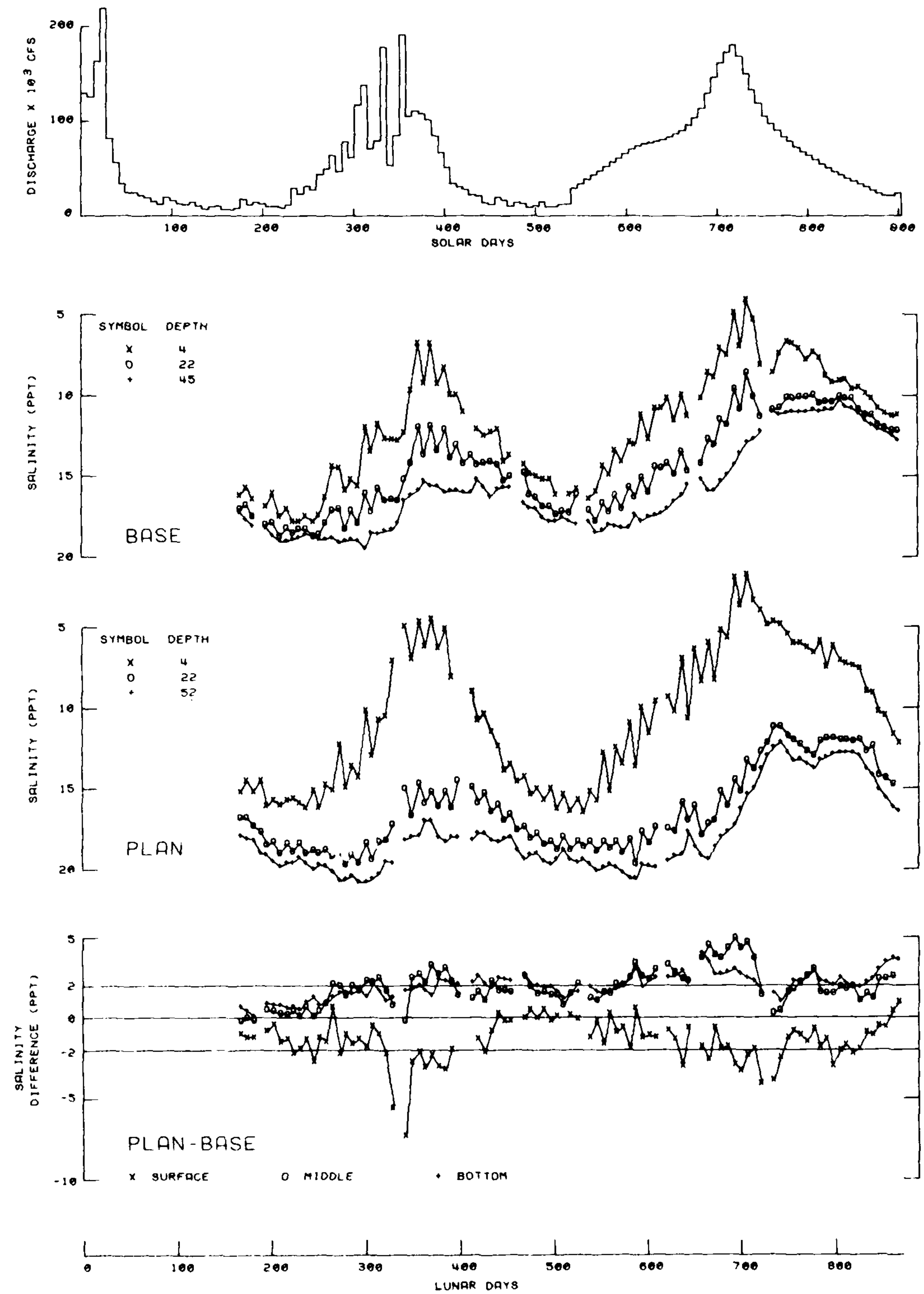


Plate 76. Sta CC-2 salinity time-history

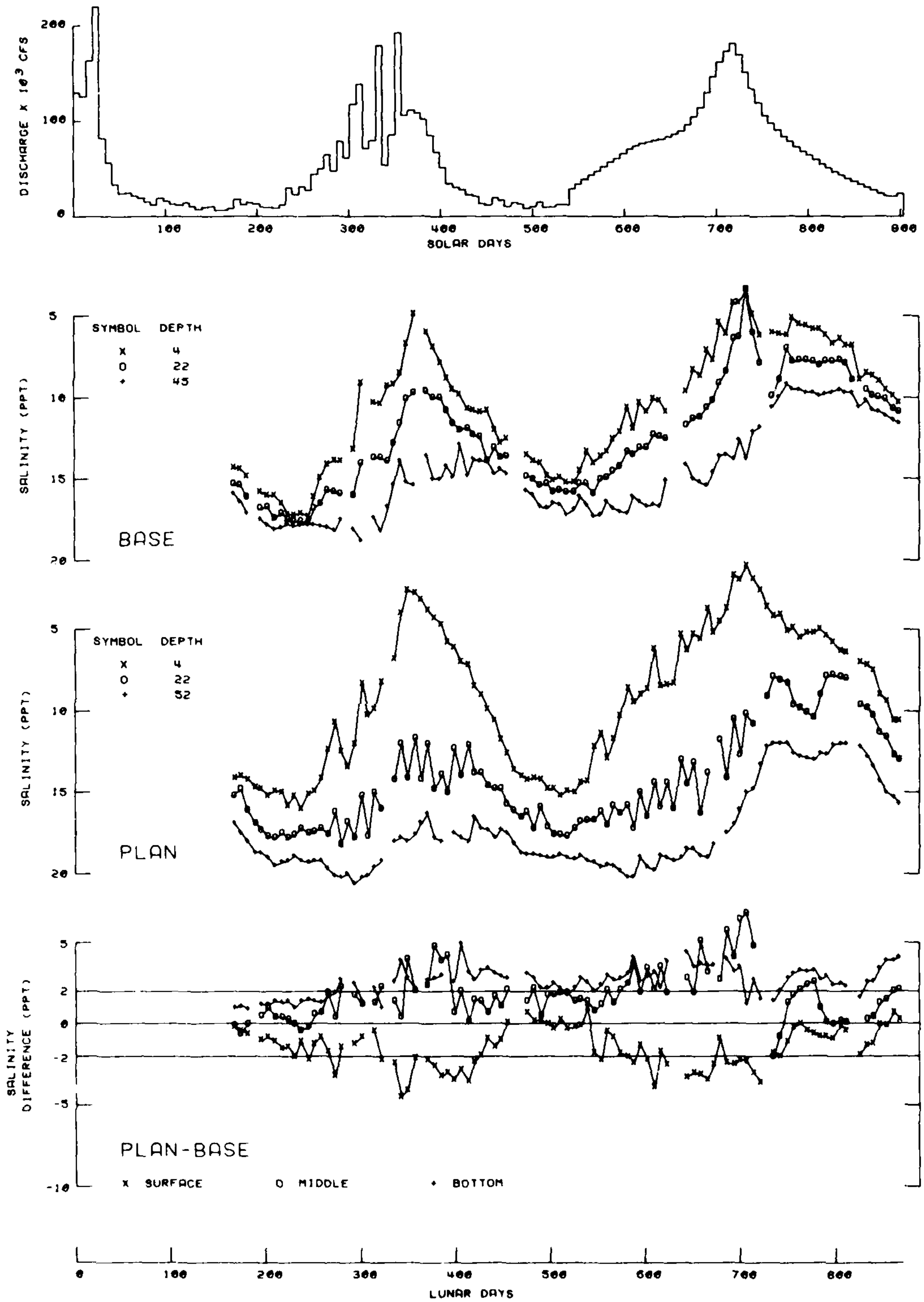


Plate 77. Sta CC-3 salinity time-history

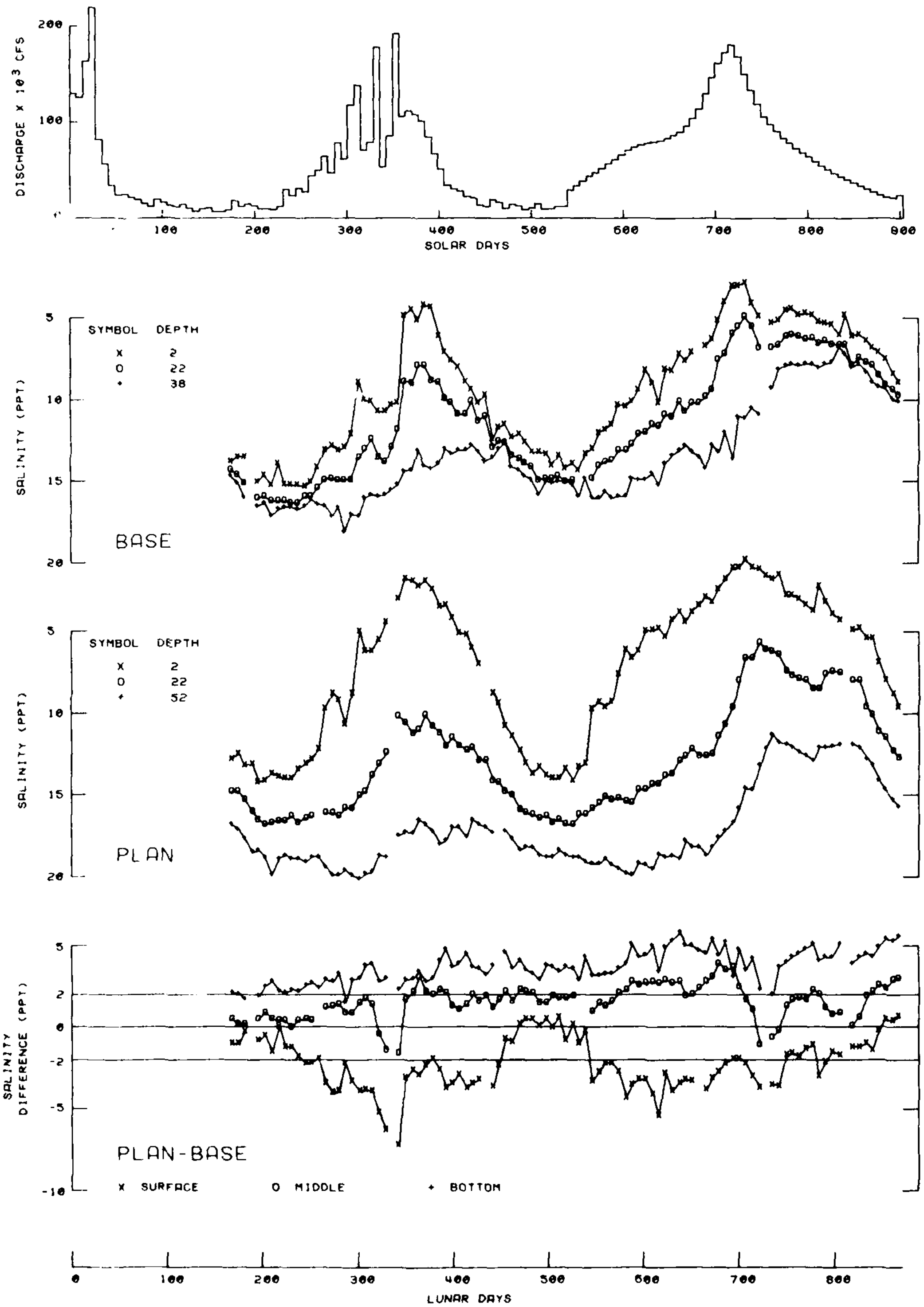


Plate 78. Sta PR-1-3 salinity time-history

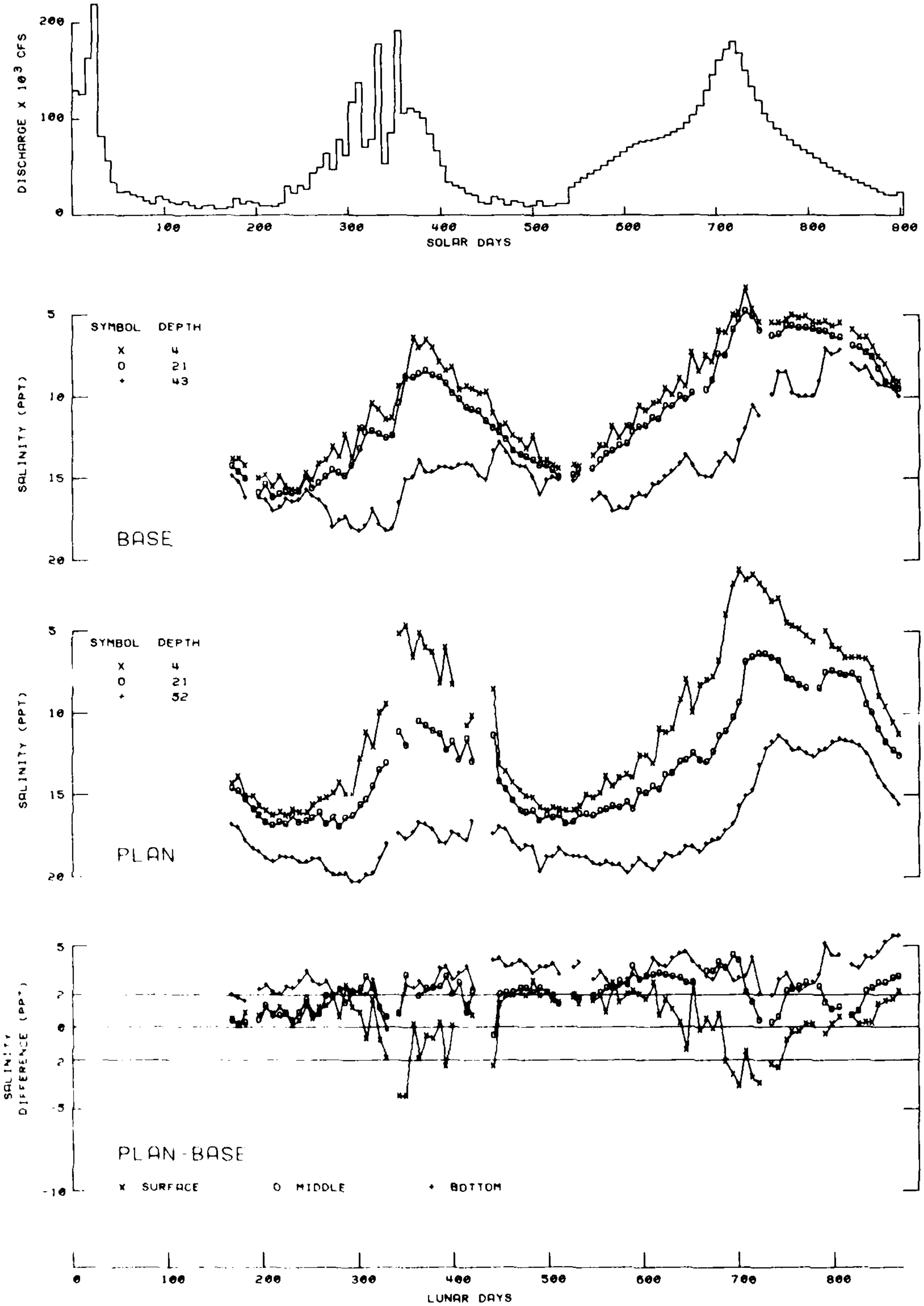


Plate 79. Sta BC-3 salinity time-history

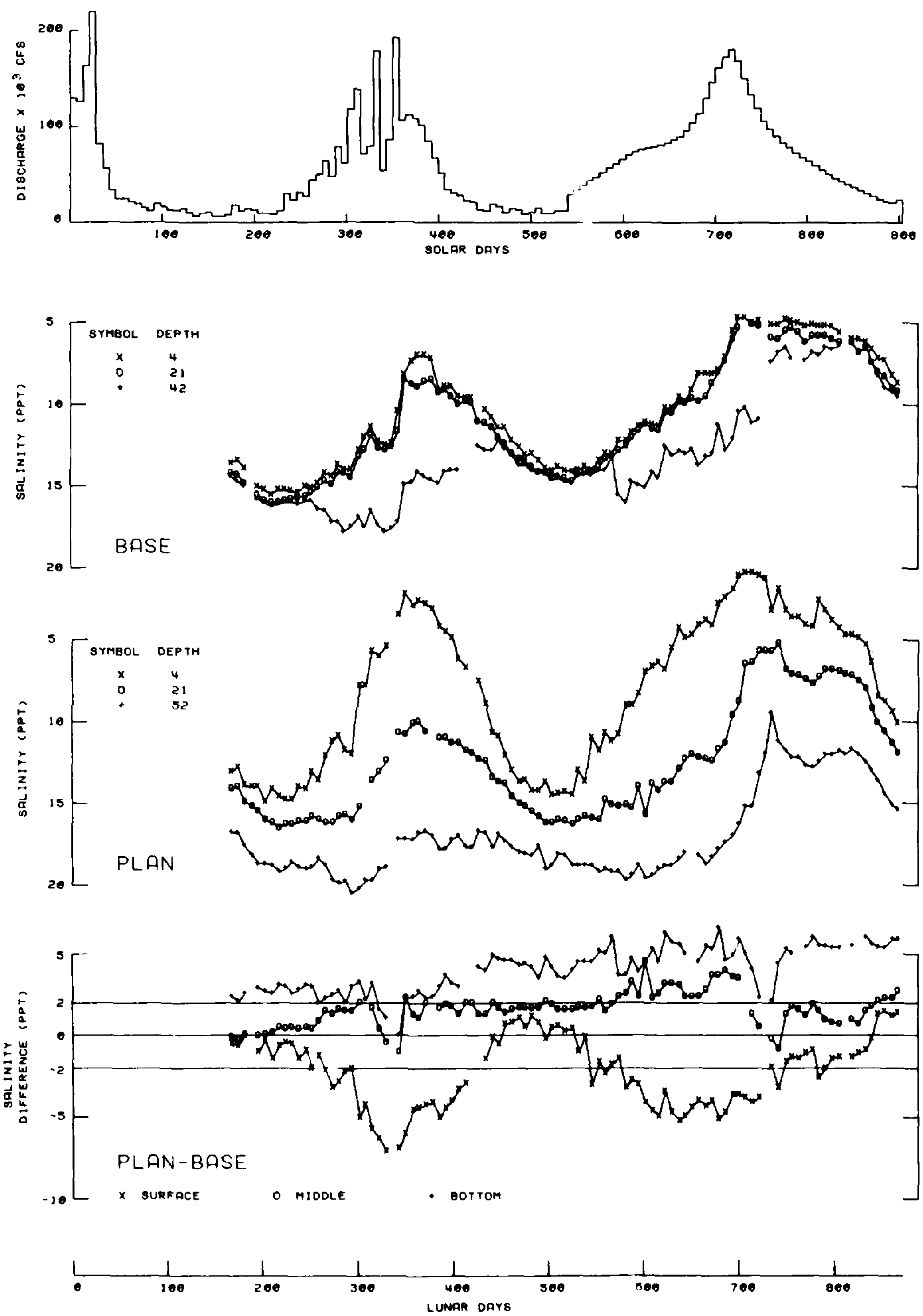


Plate 80. Sta BC-4 salinity time-history

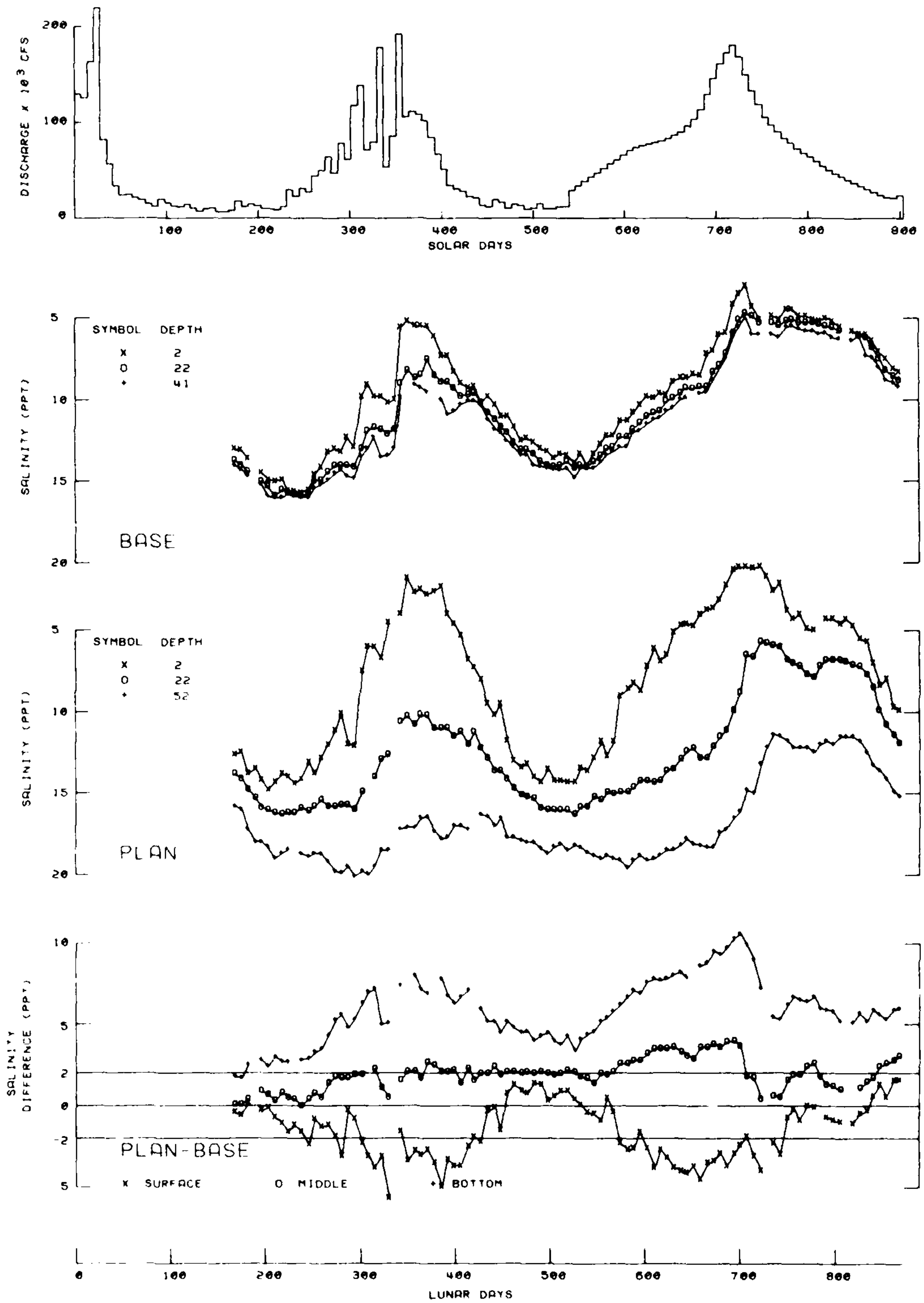


Plate 81. Sta PR-2-2 salinity time-history

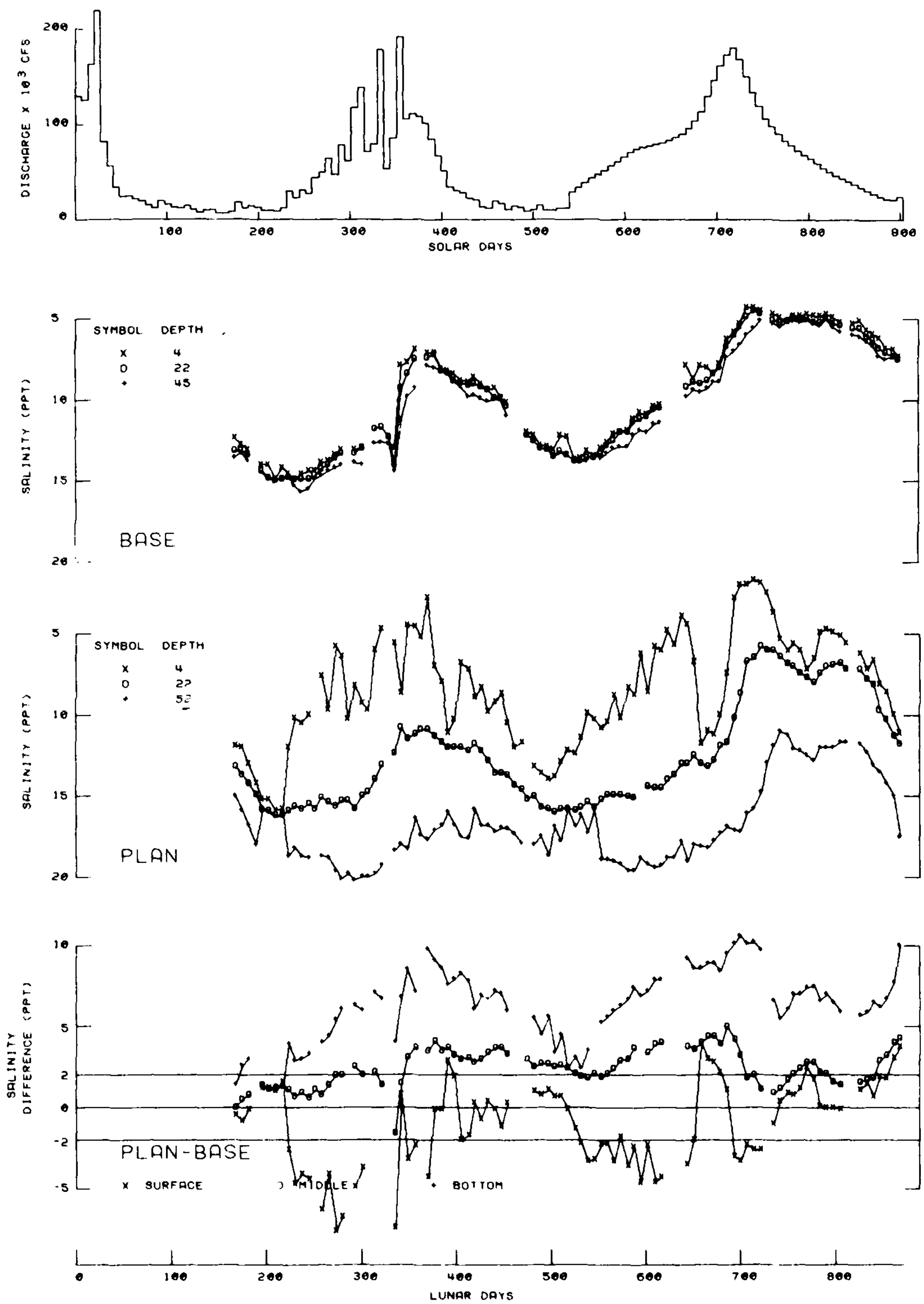


Plate 82. Sta FM-1 salinity time-history

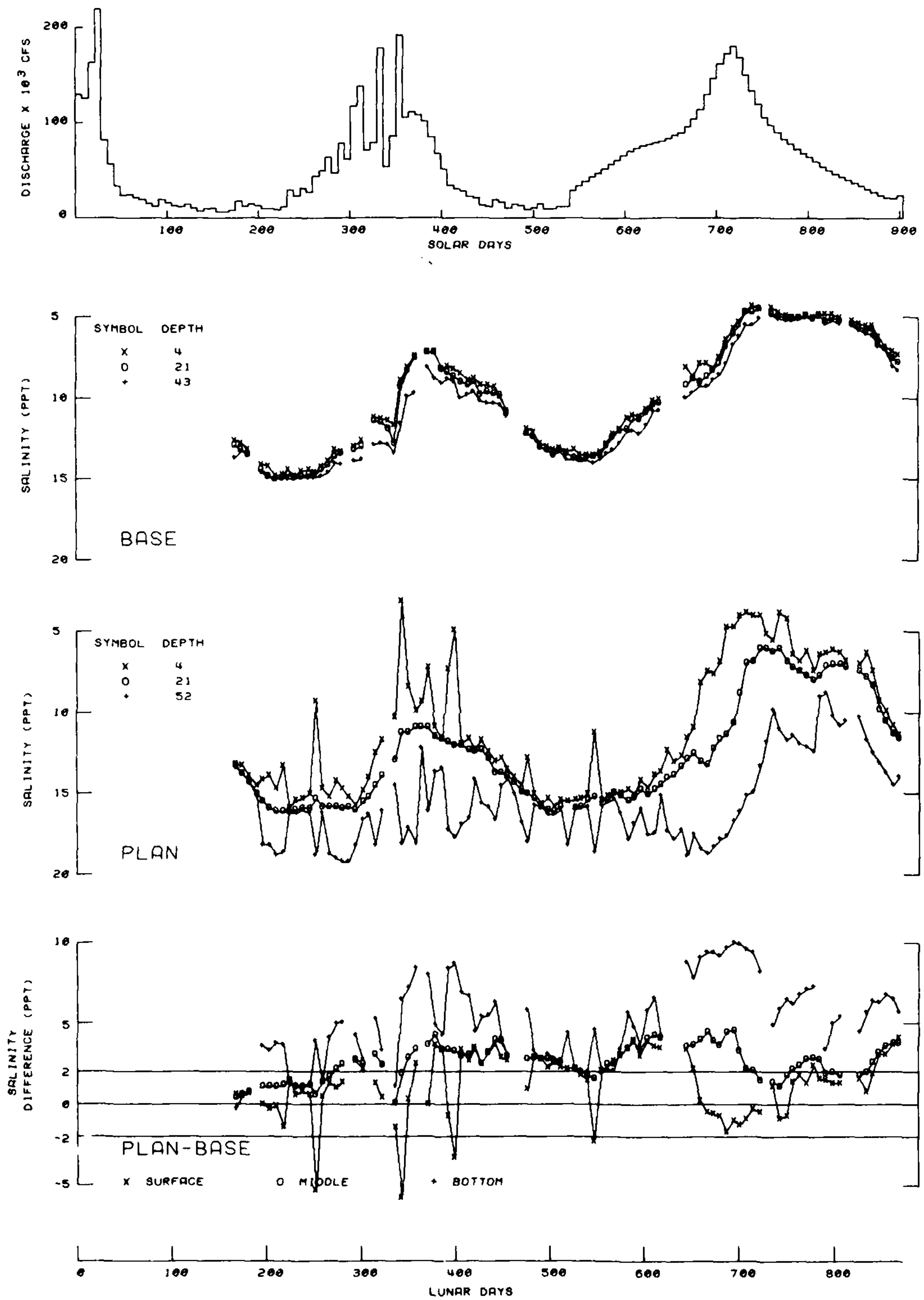


Plate 83. Sta FM-2 salinity time-history

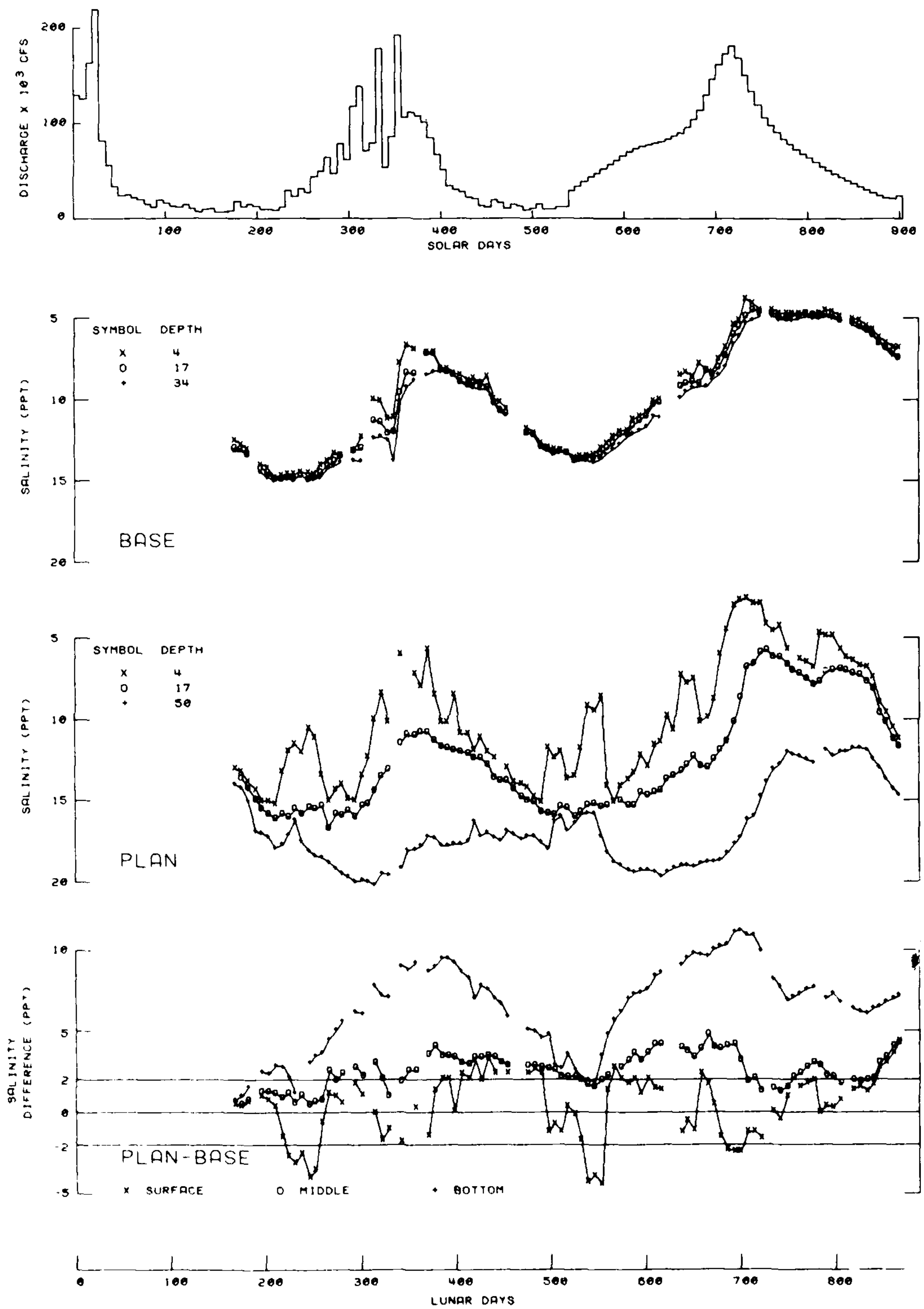


Plate 84. Sta EC-1 salinity time-history

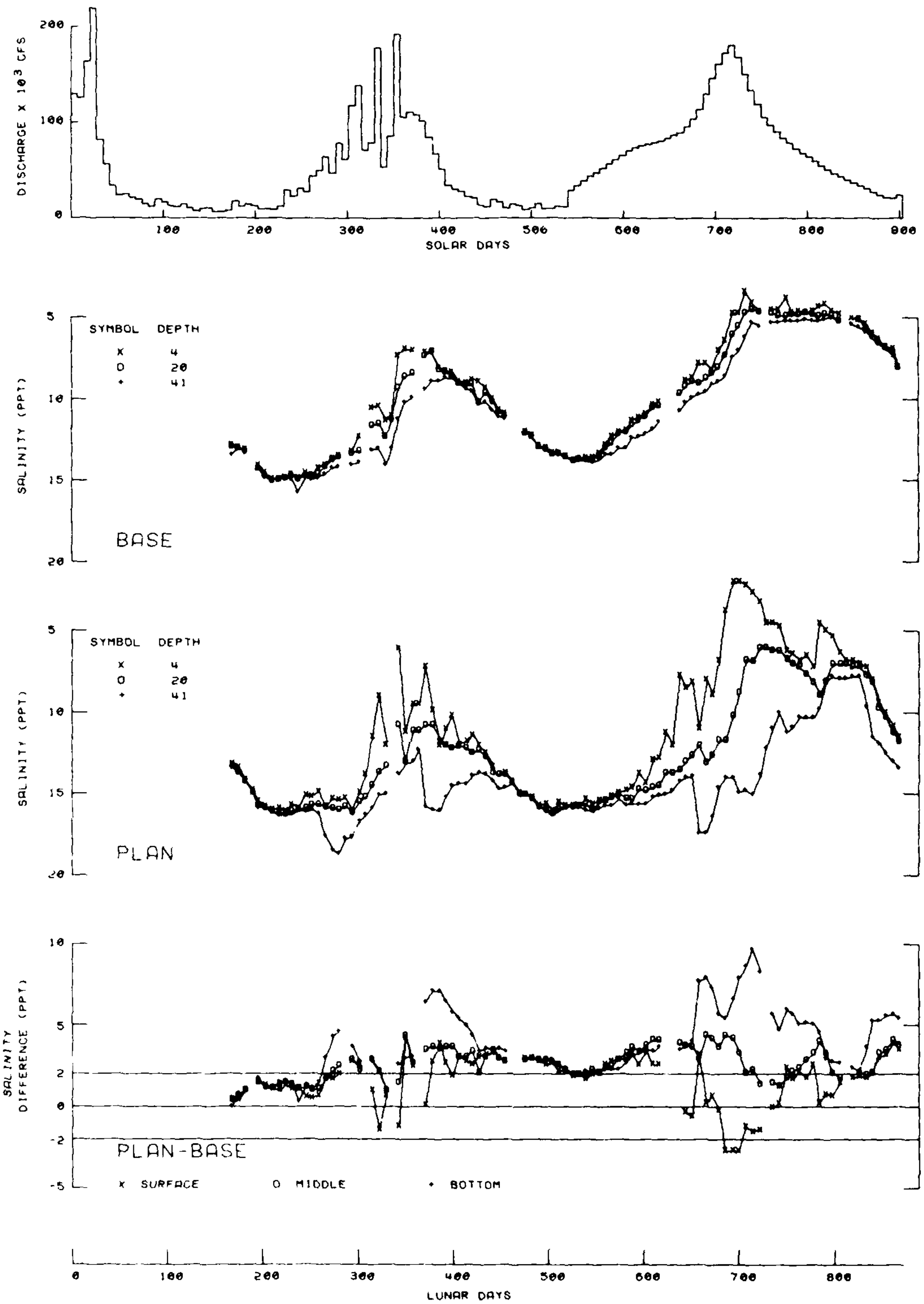


Plate 85. Sta FB-1 salinity time-history

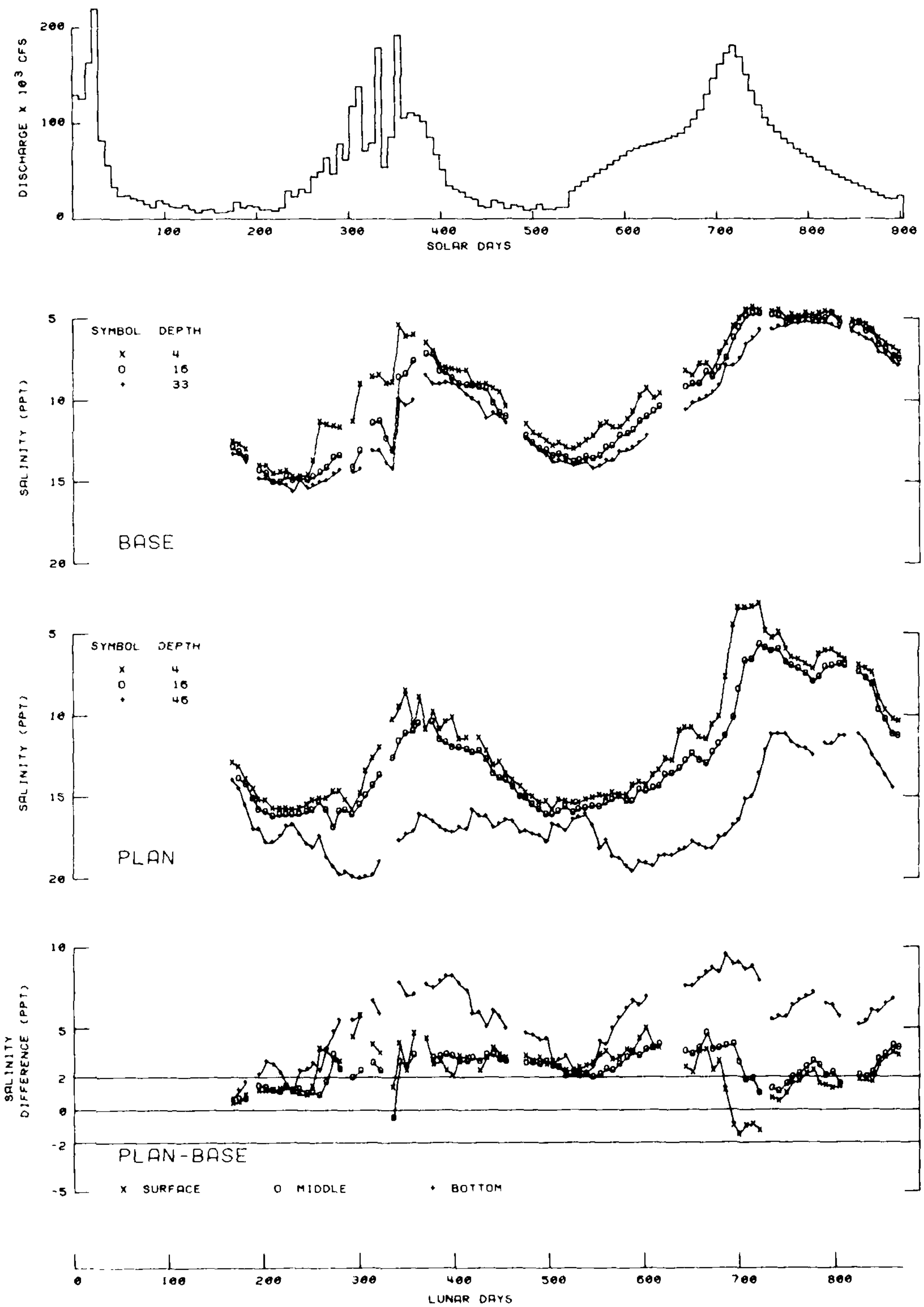


Plate 86. Sta CBC-1 salinity time-history

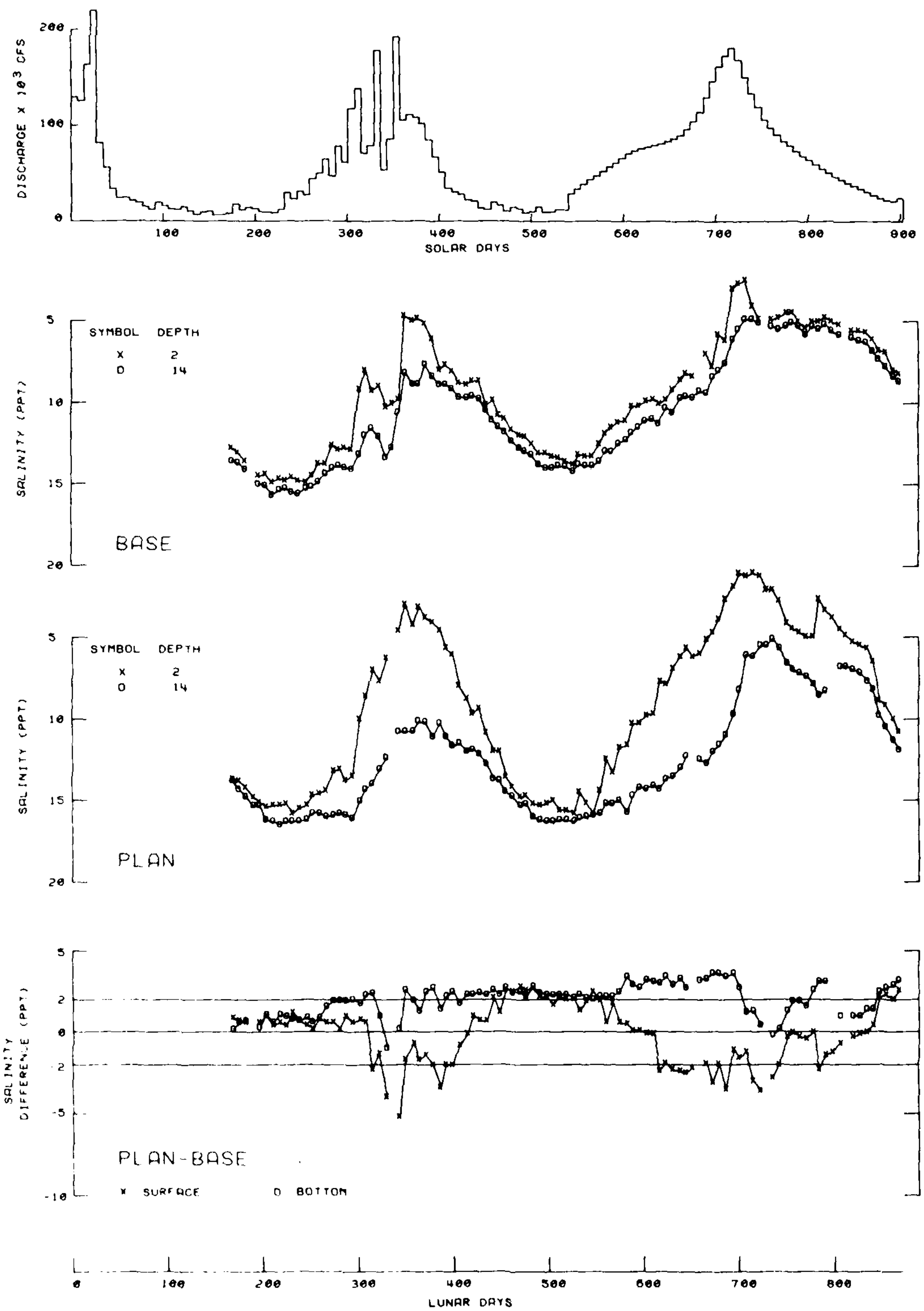


Plate 87. Sta PR-2-1 salinity time-history

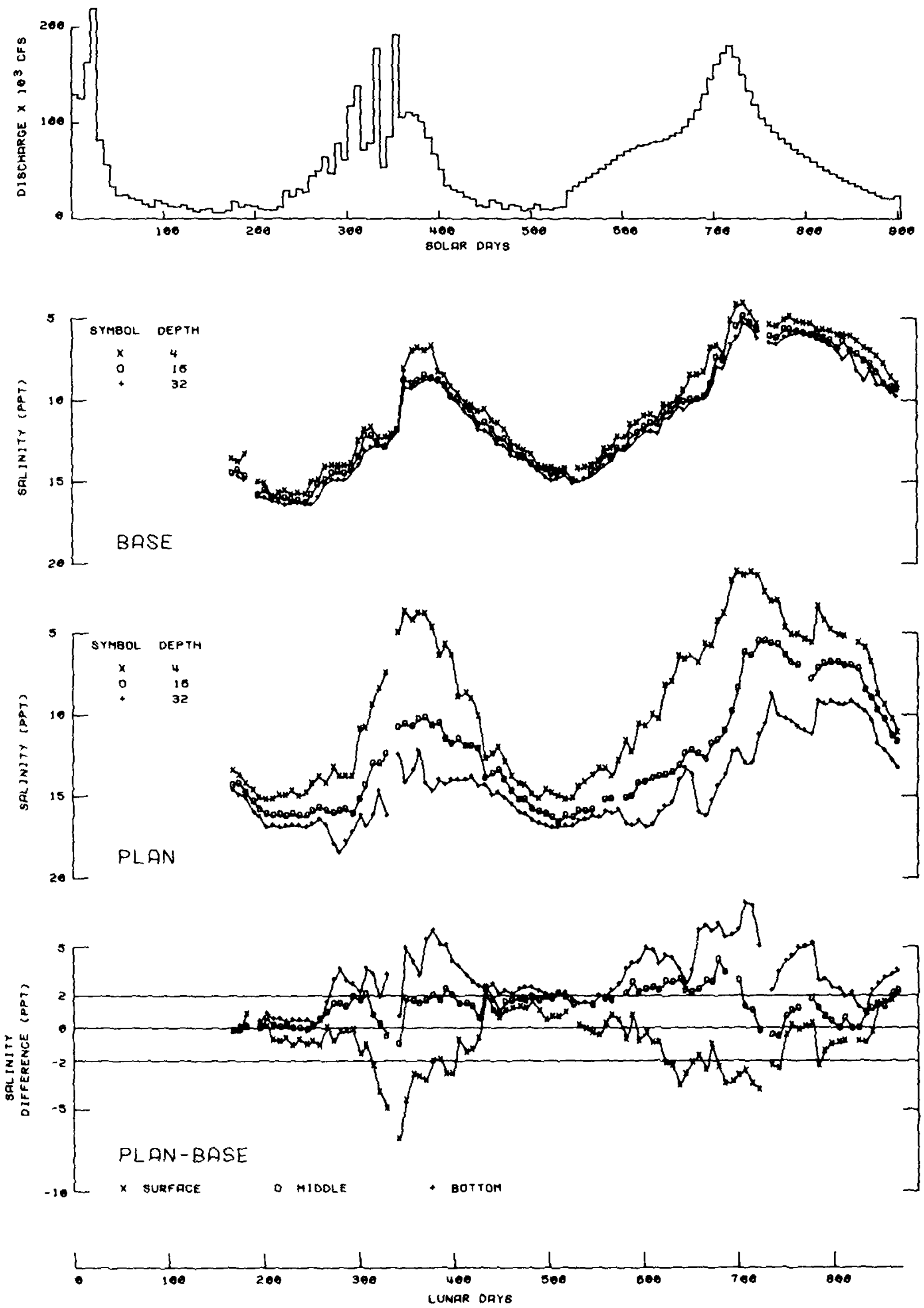


Plate 88. Sta SP-1 salinity time-history

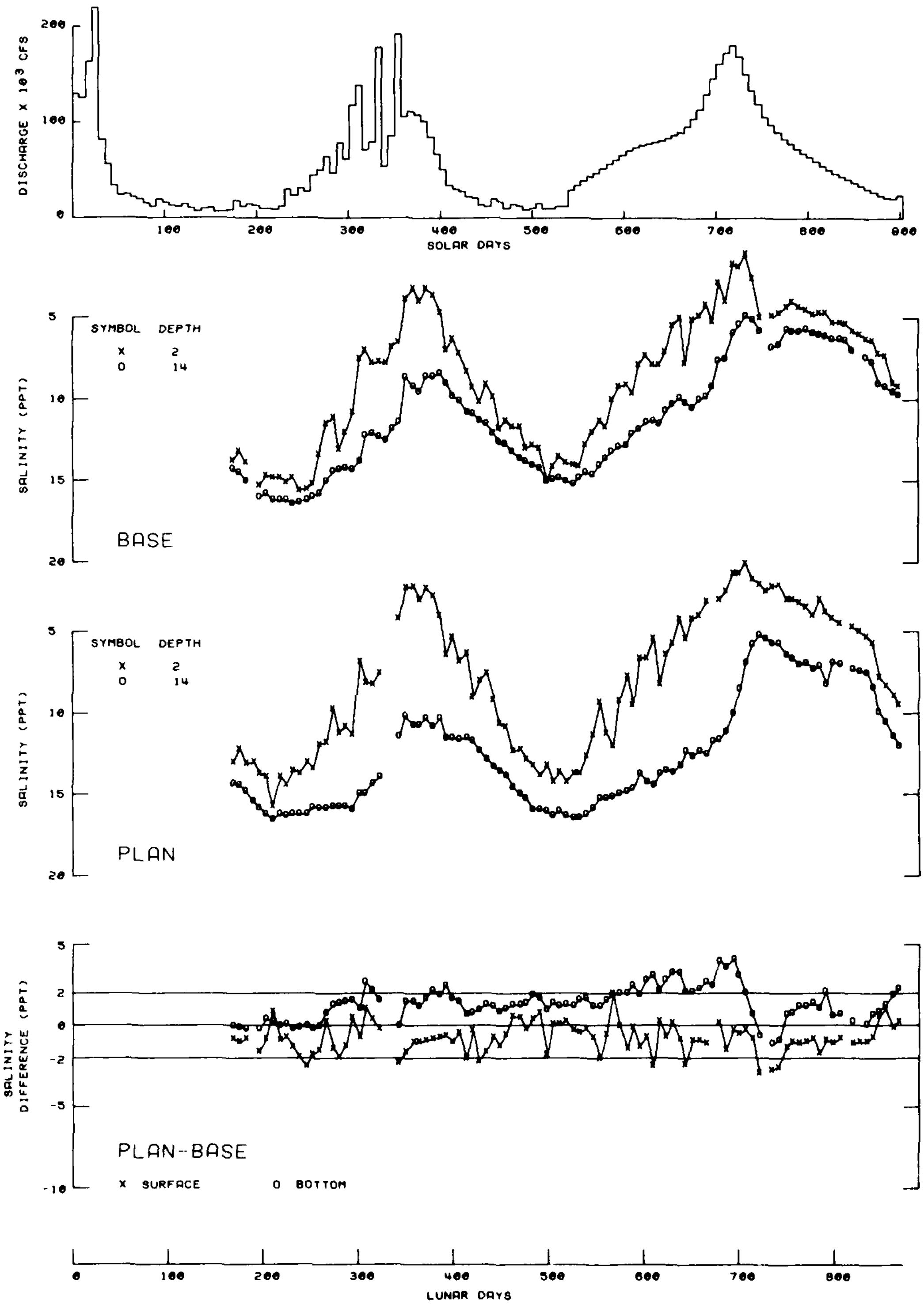


Plate 89. Sta PR-1-1 salinity time-history

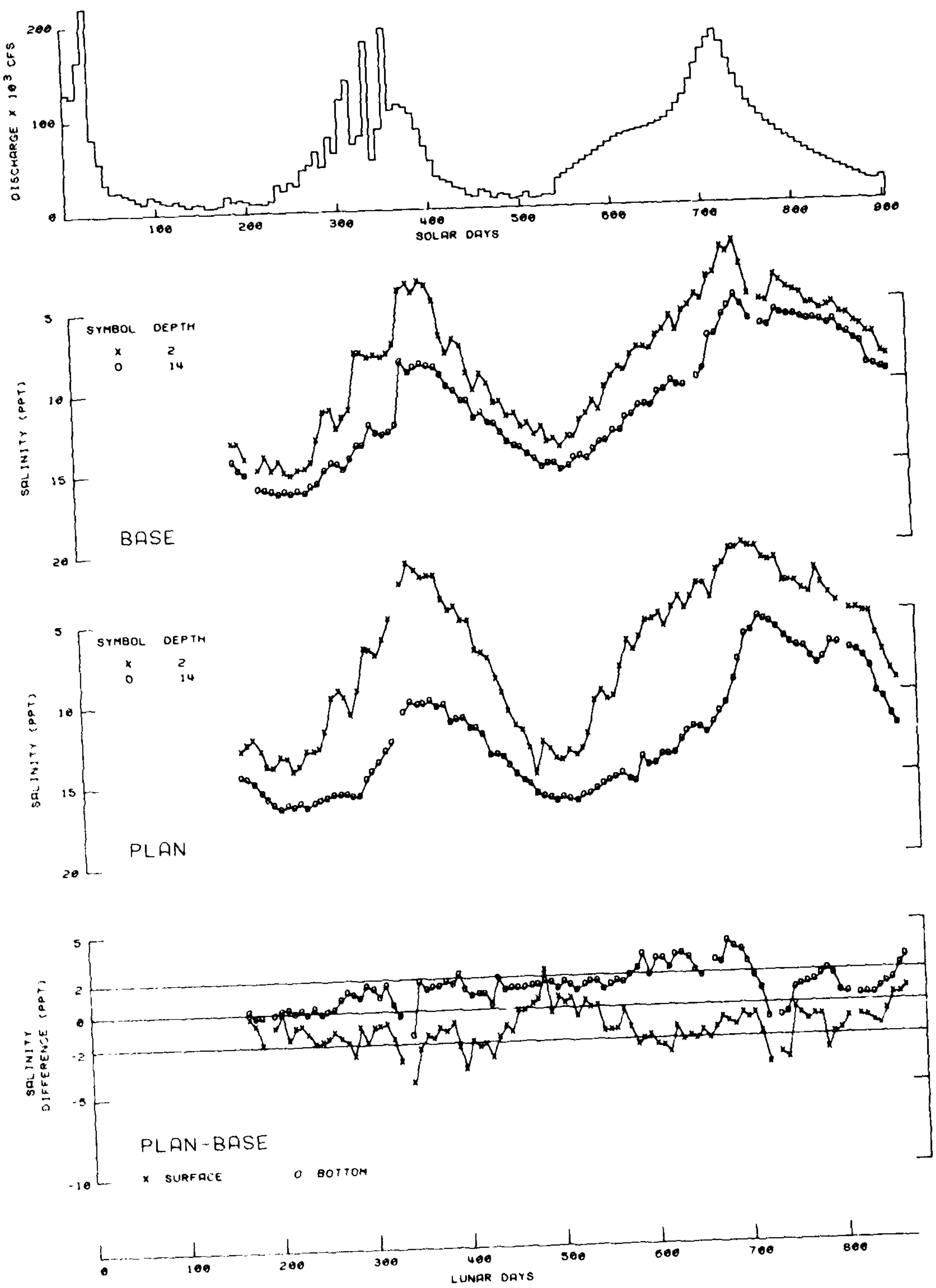


Plate 90. Sta PR-1-2 salinity time-history

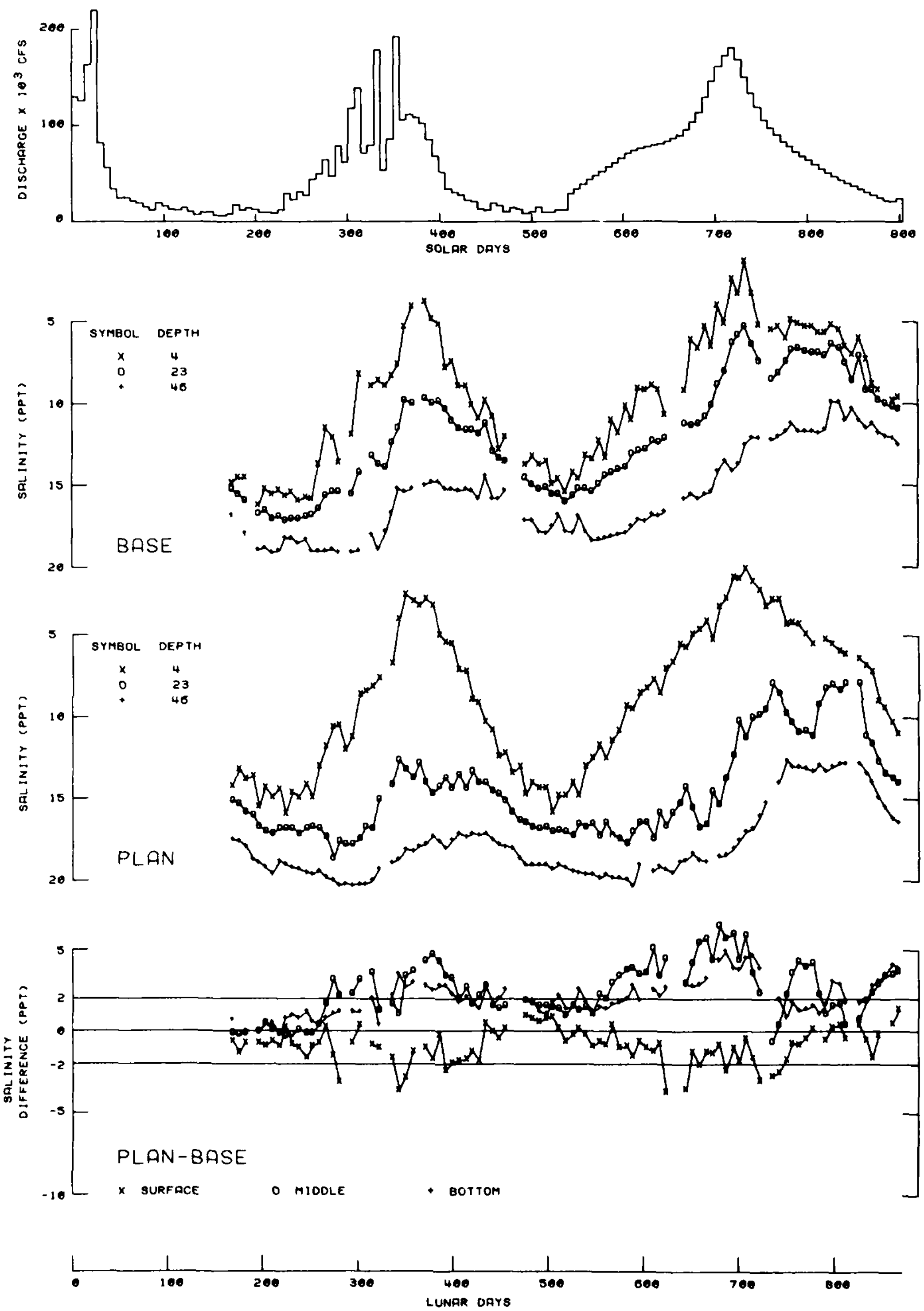


Plate 91. Sta BC-2 salinity time-history

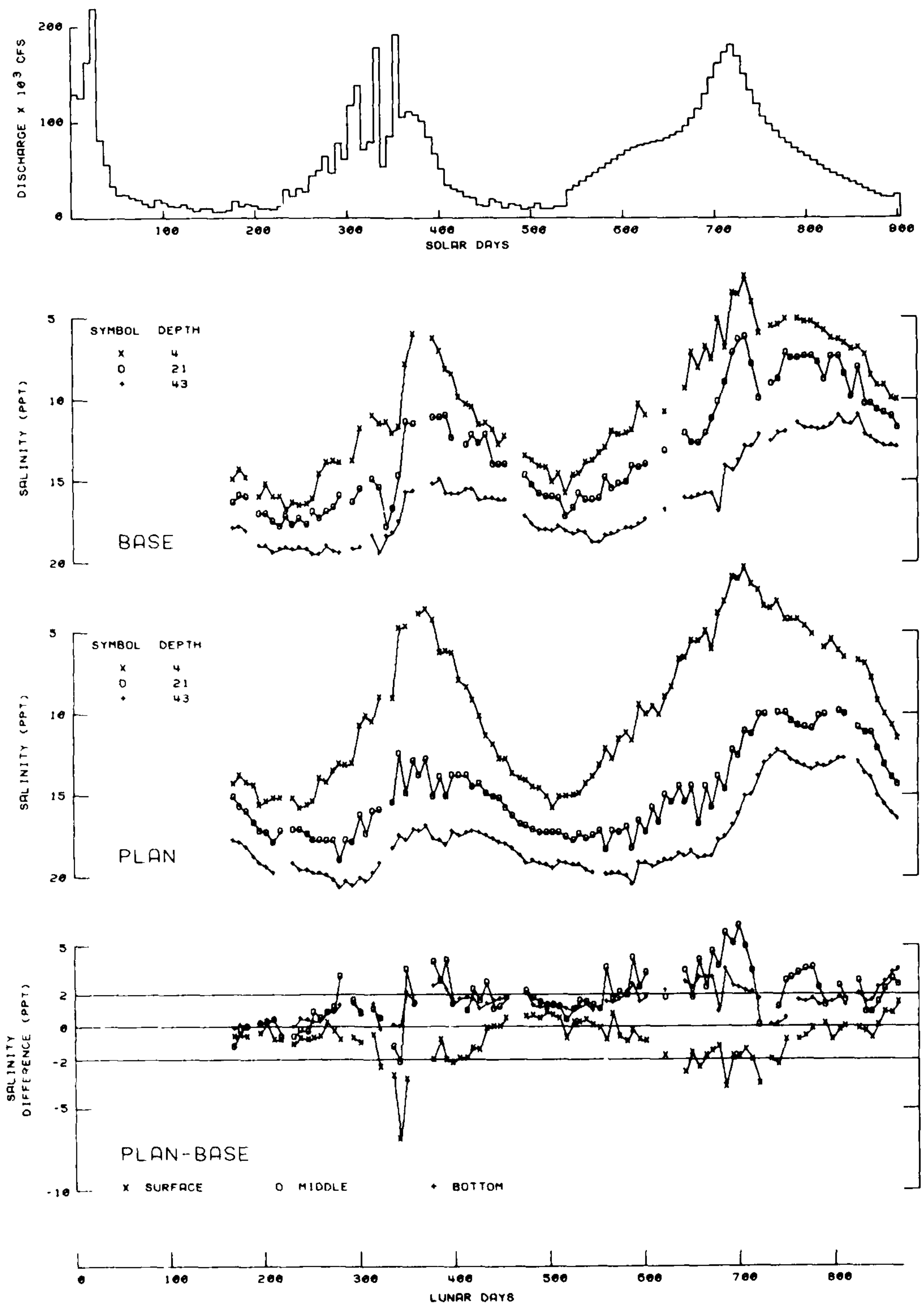


Plate 92. Sta BC-1 salinity time-history

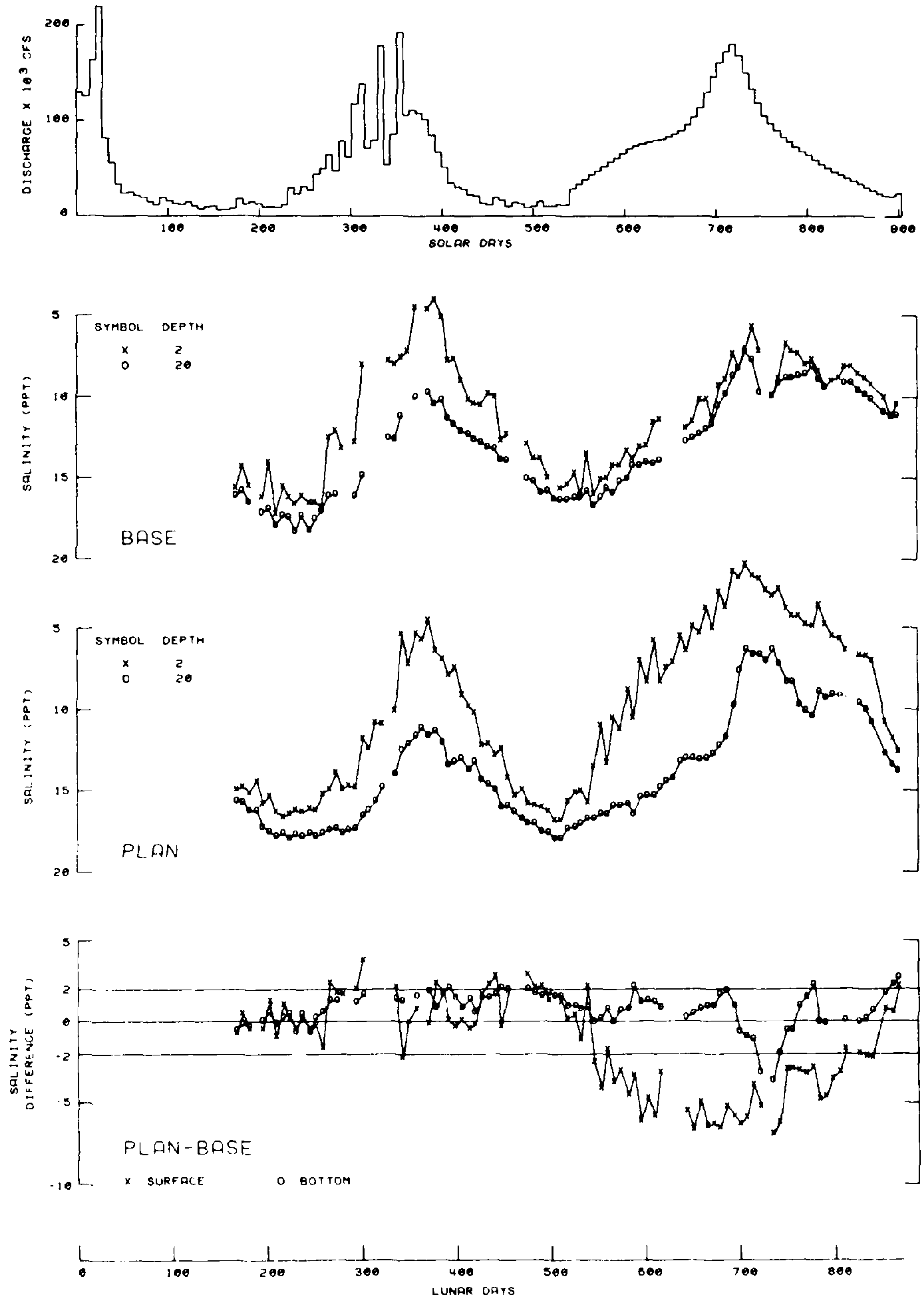


Plate 93. Sta CB-6-1 salinity time-history

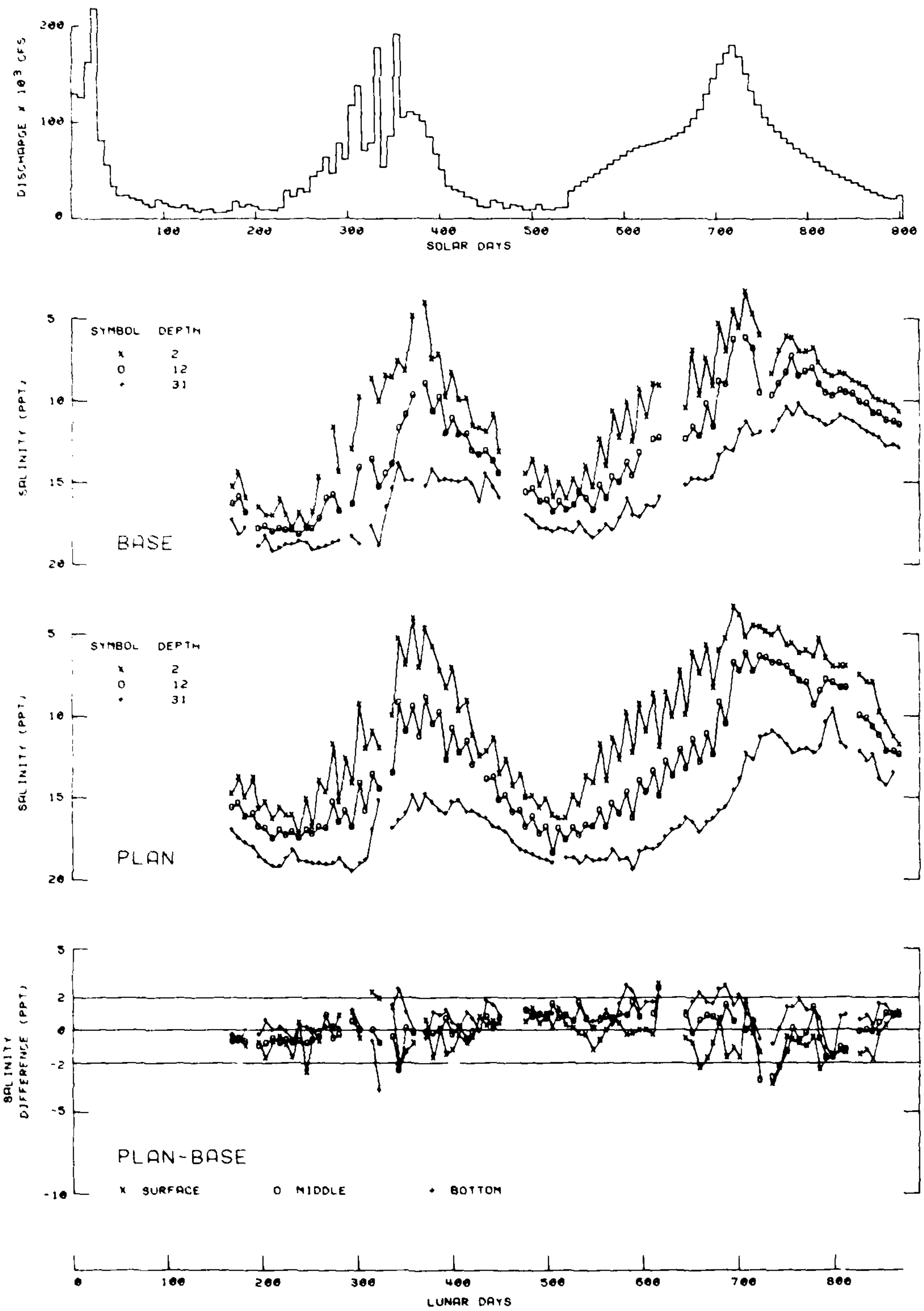


Plate 94. Sta CB-6-3 salinity time-history

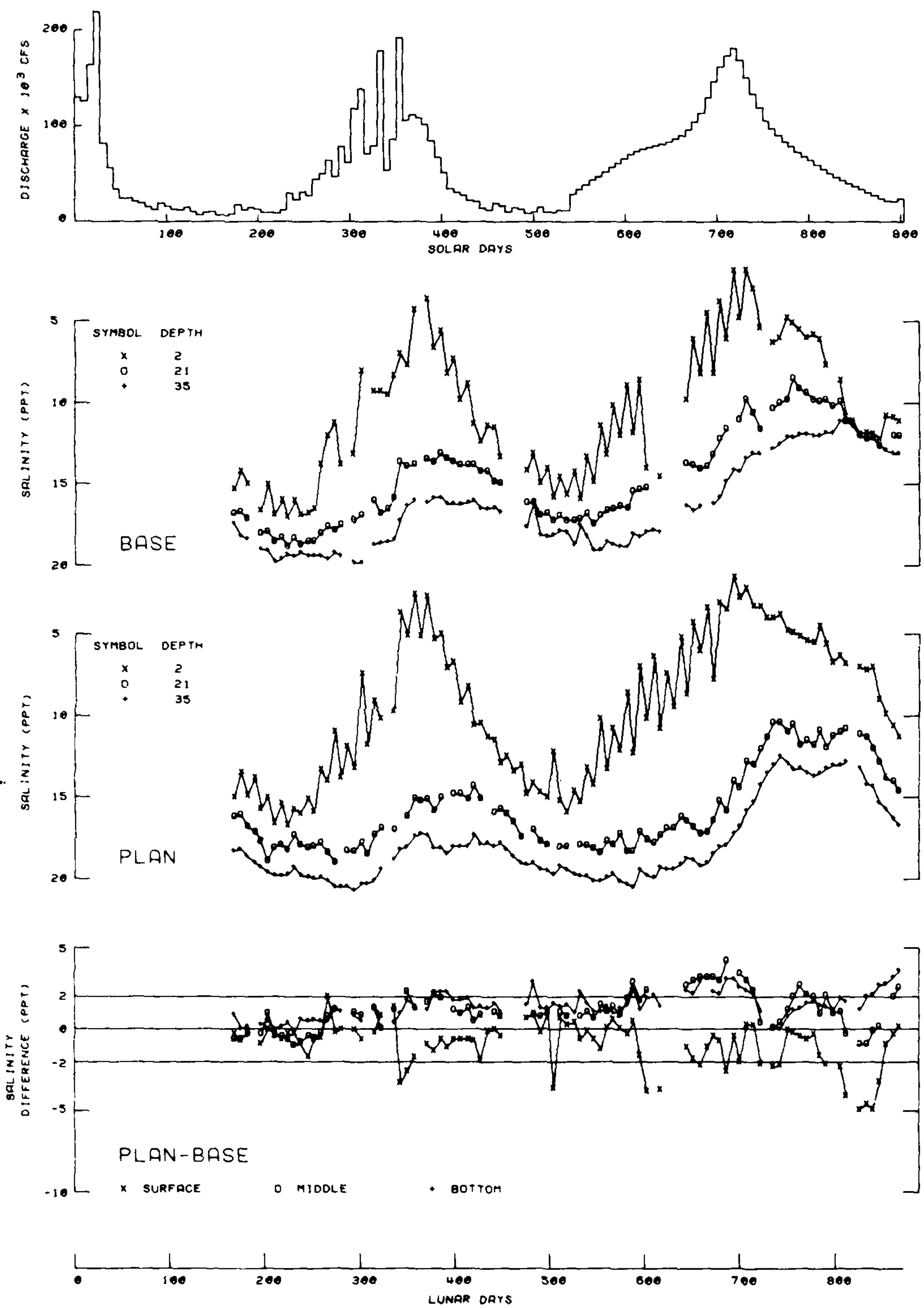


Plate 95. Sta CB-6-4 salinity time-history

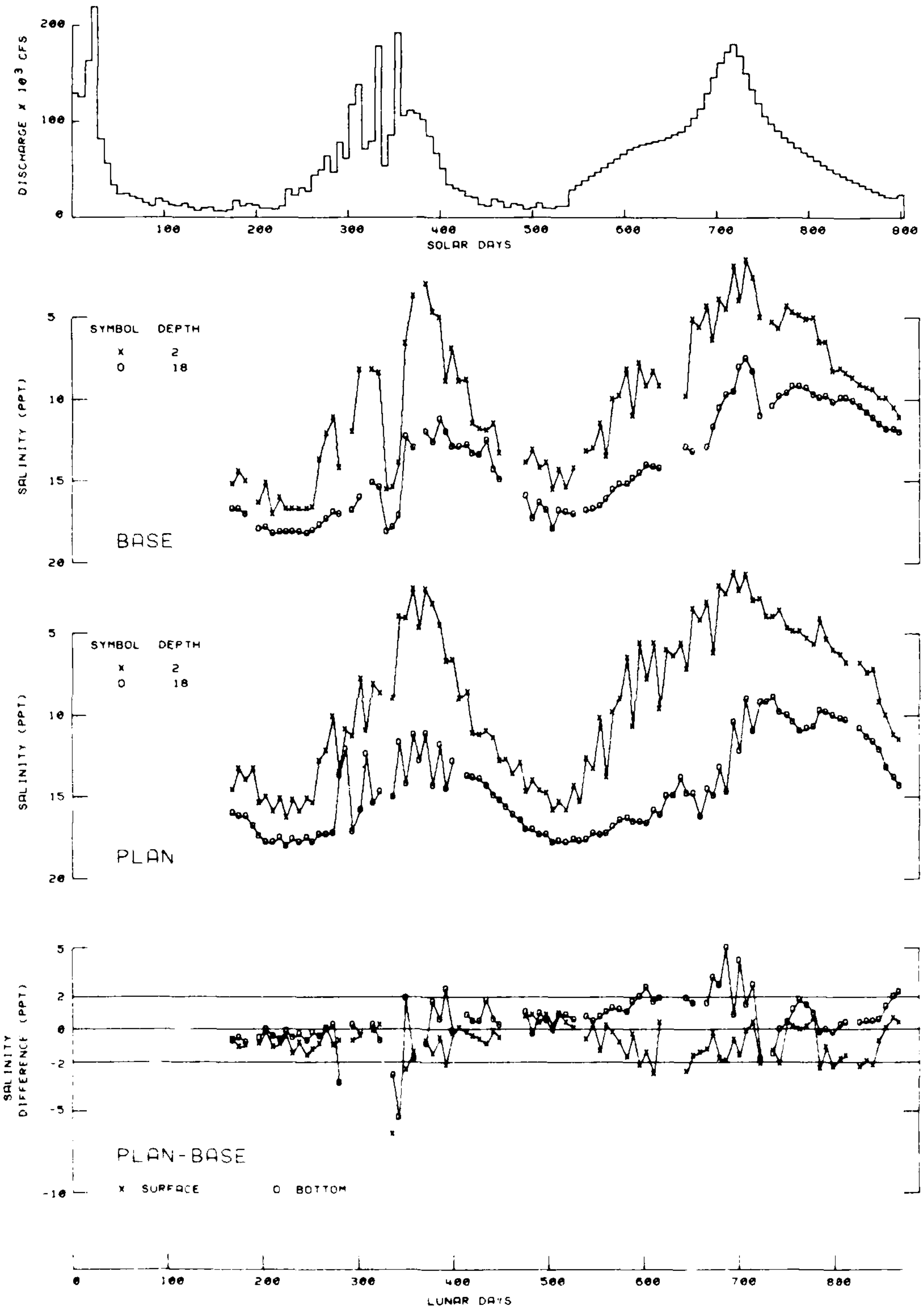


Plate 96. Sta CB-6-5 salinity time-history

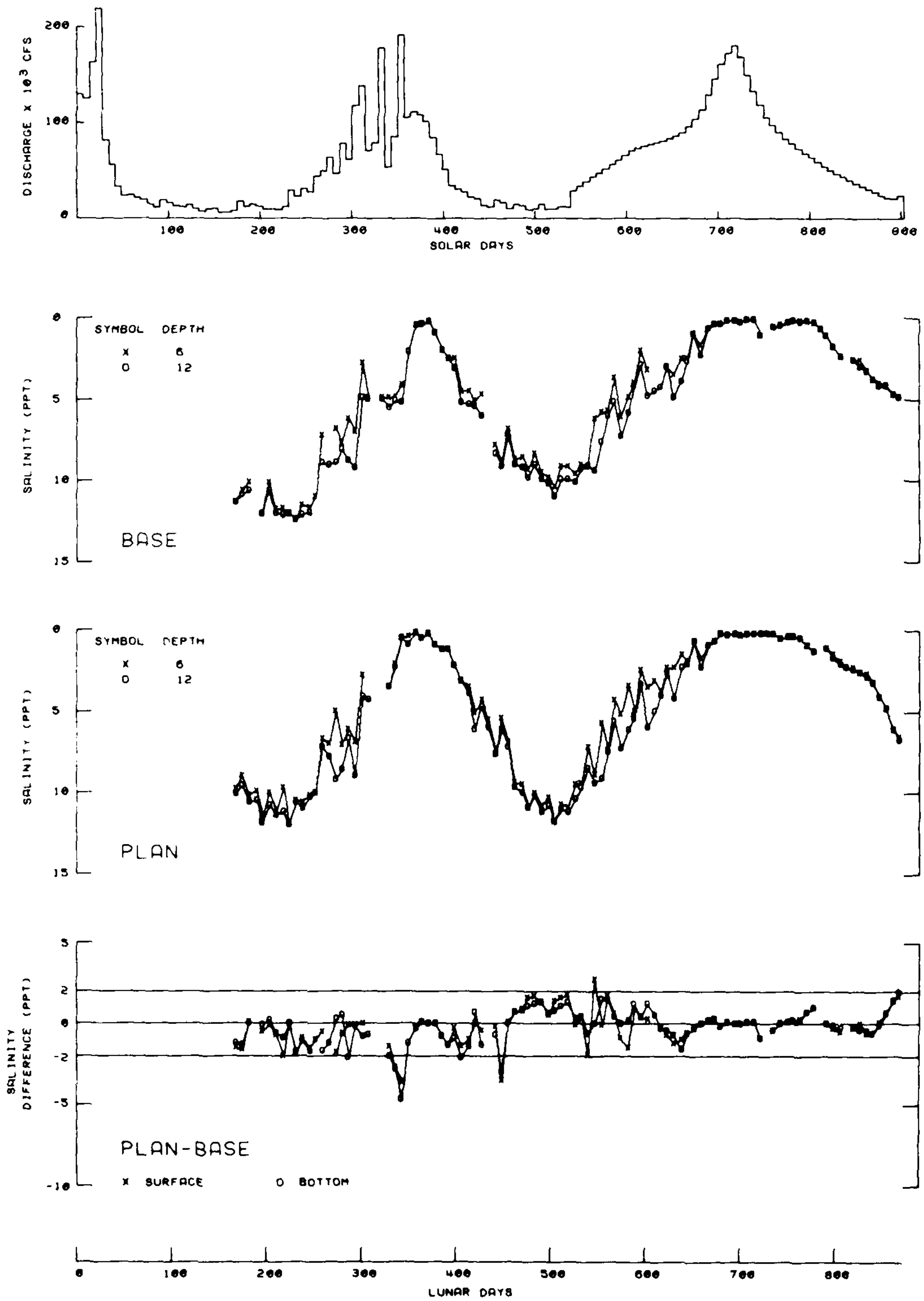


Plate 97. Sta CB-7-1 salinity time-history

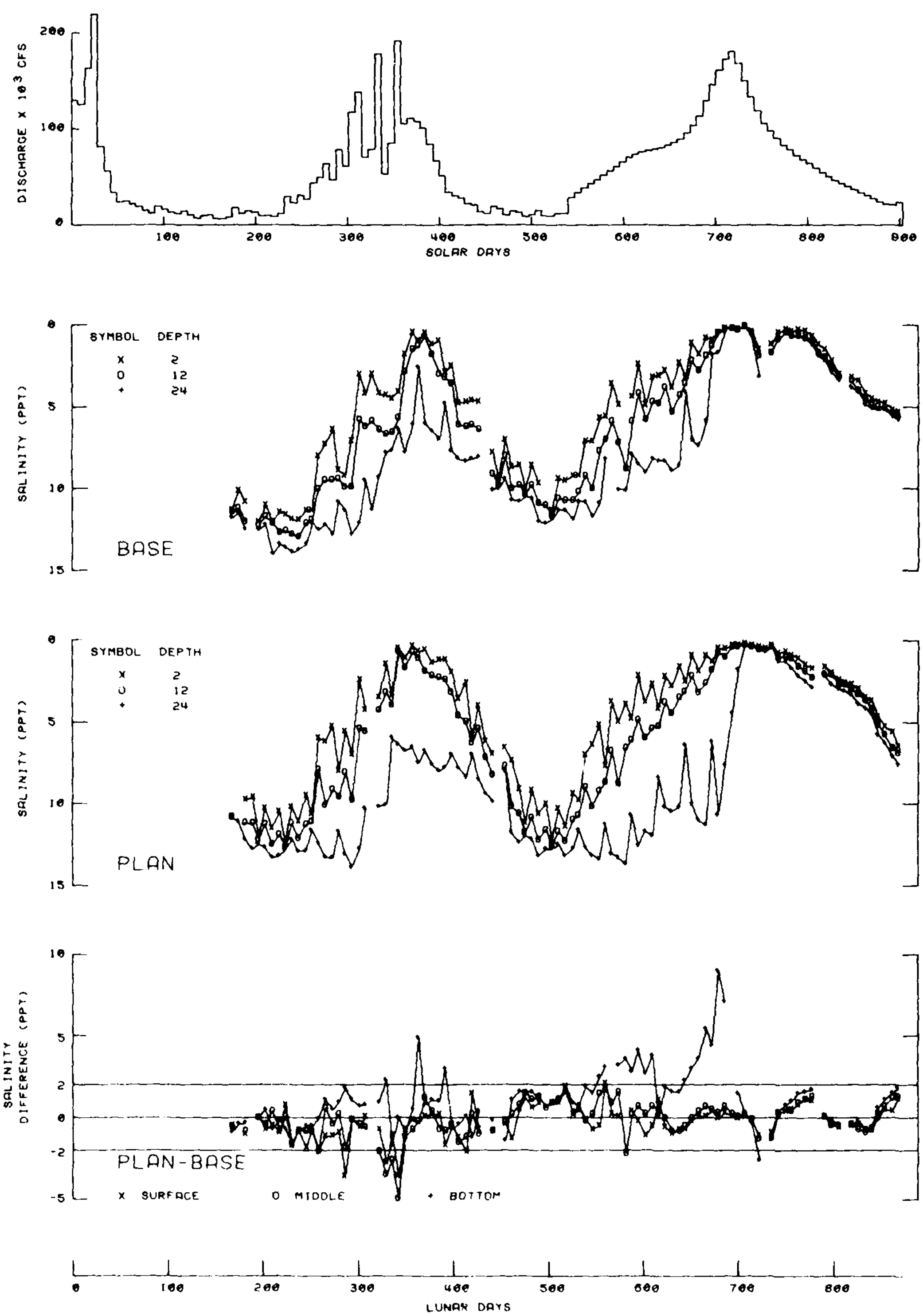


Plate 98. Sta CB-7-3 salinity time-history

AD-A114 283 ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG--ETC F/G 8/3
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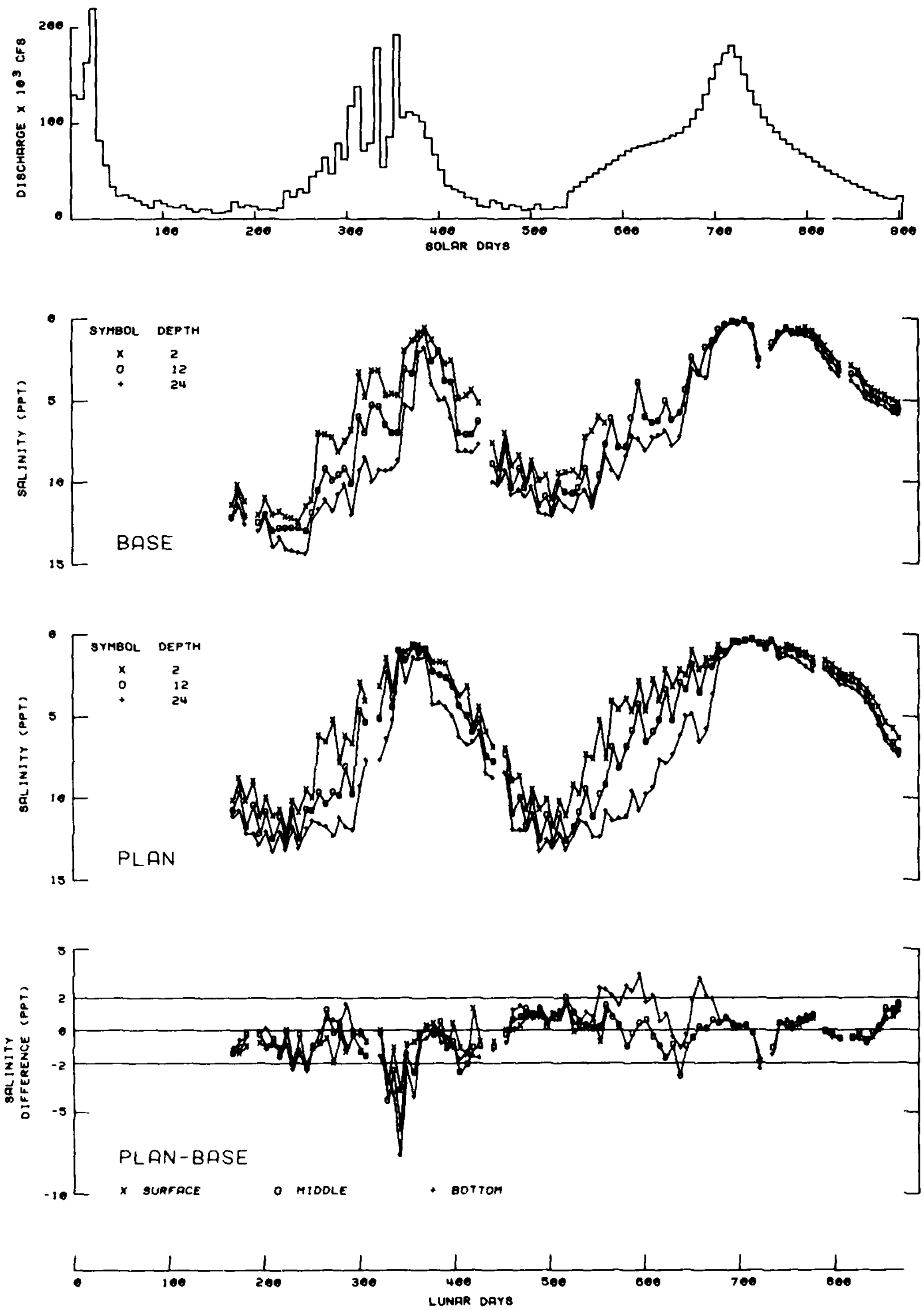

Plate 99. Sta CB-7-4 salinity time-history

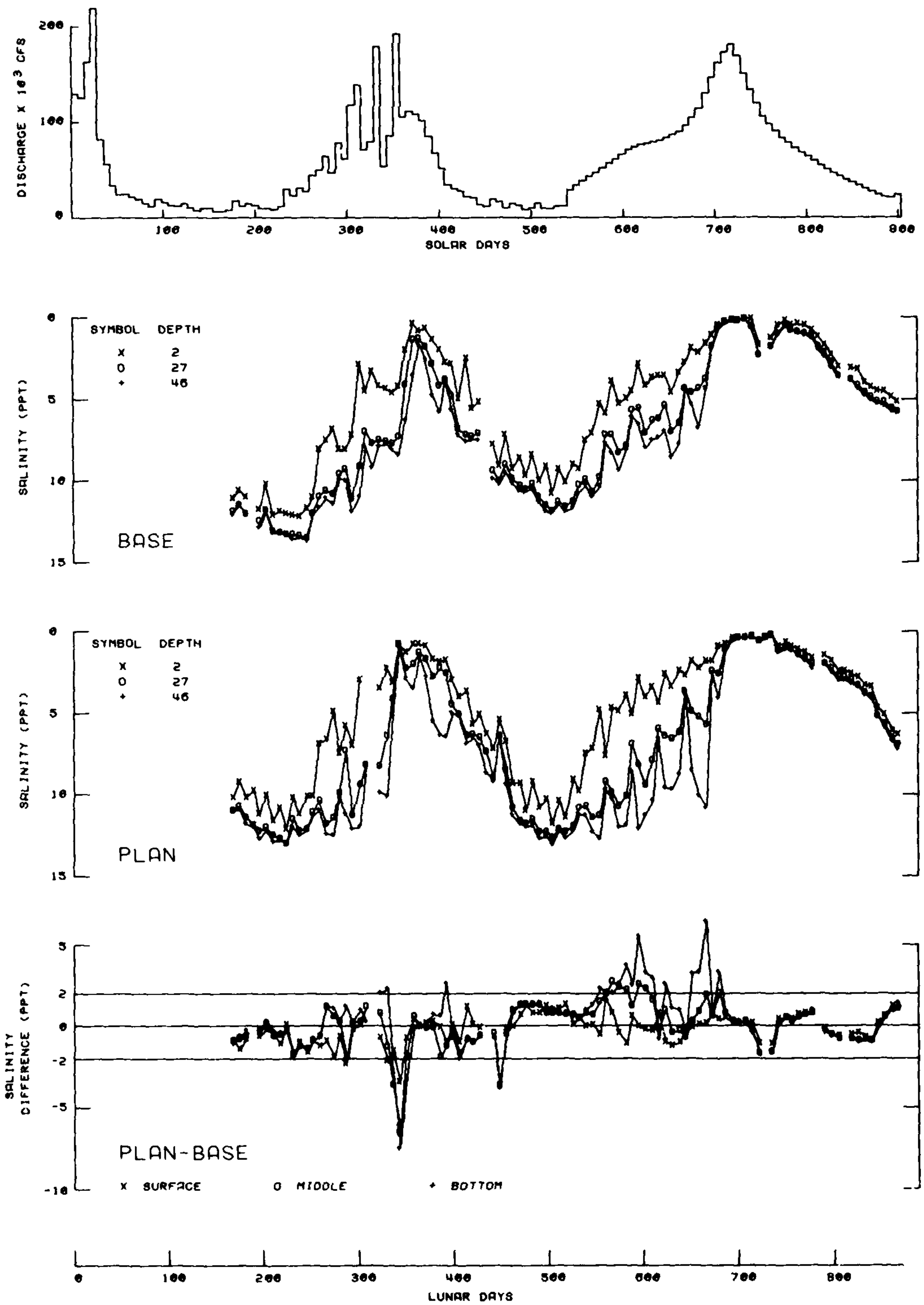

Plate 100. Sta CB-7-5 salinity time-history

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Granat, Mitchell A.
Baltimore Harbor and Channels Deepening Study : Chesapeake Bay Hydraulic Model Investigation / by Mitchell A. Granat, Leif F. Gulbrandsen (Hydraulics Laboratory, U.S. Army Engineer Waterways Experiment Station). -- Vicksburg, Miss. : The Station ; Springfield, Va. : available from NTIS, 1982.
51, [117] p., 6 folded leaves of plates : ill. ; 27 cm. -- (Technical report / U.S. Army Engineer Waterways Experiment Station ; HL-82-5)
Cover title.
"February 1982."
"Prepared for U.S. Army Engineer District, Baltimore."

1. Baltimore Harbor (Md.) 2. Channels (Hydraulic engineering). 3. Chesapeake Bay. 4. Hydraulic models. I. Gulbrandsen, Leif F. II. United States. Army. Corps of Engineers. Baltimore District. III. U.S.

Granat, Mitchell A.
Baltimore Harbor and Channels Deepening Study : ... 1982.
(Card 2)

Army Engineer Waterways Experiment Station. Hydraulics Laboratory. IV. Title V. Series: Technical report (U.S. Army Engineer Waterways Experiment Station) ; HL-82-5.
TA7.W34 no.HL-82-5

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